ASSET MANAGEMENT PRACTICES

PENROSE CABLE FIRE INVESTIGATION

Transpower New Zealand Limited

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Keeping the energy flowing

Transpower New Zealand Limited The National Grid

Version Control

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1.0	Electricity Authority	Issued with batch 2 of submissions	16/12/2014
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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 Vector cables in a trench at Transpower's Penrose substation on Sunday 5 October 2014.

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1. INTRODUCTION

Between 2:10am and 2:30 am on Sunday 5 October, a number of Transpower assets at Penrose substation tripped as a result of a fire in a cable trench containing Vector's distribution power cables.

The fire caused damage to Vector's distribution cables, leading to feeder trippings and extensive loss of supply in the distribution network. The fire also caused damage to Transpower control cables passing across the distribution cable trench, leading to the tripping of some transmission equipment.

To allow safe access for fire fighters, Transpower isolated all electrical supplies to the 220 kV and 33 kV switchyards at Penrose. This resulted in an interruption affecting consumers in the Auckland suburbs of Mt Wellington, Onehunga, Ellerslie, St Johns, Remuera and St Heliers.

Once the fire had been extinguished, Transpower was able to restore some of the 220 kV and 33 kV transmission equipment. By around 3:30pm on Sunday 5 October, Vector was able to begin progressively restoring supply to affected customers, using temporary power cables to bypass the areas of fire damage. Supply was largely restored by Vector on the morning of Tuesday, 7 October, but with reduced security.

A combined investigation was launched, led by independent investigators appointed by Transpower and Vector.

In addition, the Minister of Energy and Resources has requested the Electricity Authority to prepare a report on the incident.

This report presents a review of Transpower asset management practices, as part of the investigation into the Penrose cable fire incident. The report focuses on the management of risk in Transpower's asset management framework, with specific attention to Penrose.

2. TRANSPOWER'S ASSET MANAGEMENT SYSTEM

2.1 Introduction

Asset management is described as "*the coordinated activities of an organisation to realise value from assets*."[1]

Asset management direction and control requires the definition and implementation of:

- an asset management policy
- an asset management strategy and objectives
- asset management plans, processes, procedures and activities
- a range of 'enablers', such as asset management information systems, an asset management competence framework, and the review processes that

[1] ISO 55000 International Standard for Asset Management

are needed to necessary to continuously improve asset management activities.

In submissions to the Commerce Commission in 2011, Transpower made a commitment to enhance its asset management framework, and to work towards accreditation to the publicly available specification BSI PAS55:2008 – *Asset Management*. The following sections outline Transpower's asset management framework, external reviews of the asset management framework, and the achievement of accreditation to PAS55 in July 2014.

2.2 Asset Management Framework

Transpower's Asset Management Framework (AMF) provides the direction of its asset management activities. The Framework recognises that clear connectivity between the organisational strategic plan and the on-the-ground lifecycle activities forms the basis of a robust AMF.

Key documents that form part of Transpower's Asset Management Framework are published on Transpower's website.[2]

Figure 1 provides an illustration of the key elements of Transpower's AMF. These key elements concentrate on:

- clear "line of sight" from business drivers to our asset management plans
- delivery of customer value
- feedback and continuous improvement
- asset lifecycle activities

[2] https://www.transpower.co.nz/about-us/industry-information/asset-management-framework

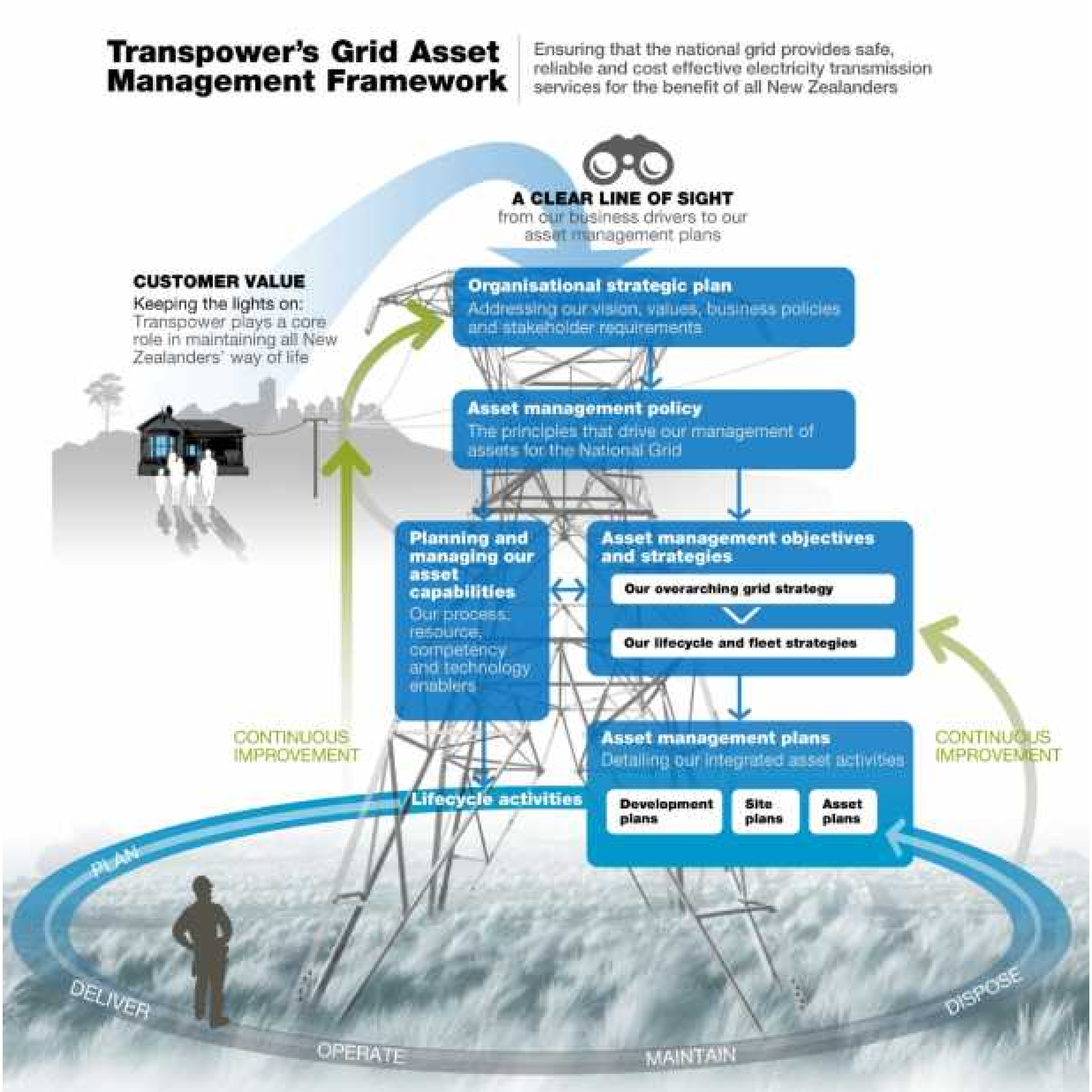

Figure 1 Transpower's Grid Asset Management Framework

2.3 Regulatory review of asset management

Transpower is subject to Individual Price-Quality Path (IPP) regulation by the Commerce Commission, under Part IV of the Commerce Act. The regulatory process requires Transpower to submit expenditure forecasts and quality performance targets in advance for defined regulatory periods. The expenditure forecasts and quality performance targets are supported by detailed submissions that describe Transpower's asset management systems and practices.

Expenditure forecasts and quality targets were submitted to the Commerce Commission in February 2011 for the RCP1 period (1 July 2012 to 31 June 2015), and in December 2013 for the RCP2 period (1 July 2015 to 30 June 2020).

The regulatory process includes detailed review of many aspects of Transpower's asset management systems and practices. For the RCP2 process, the Commerce Commission engaged independent consultants to provide a technical review of

Transpower's RCP2 expenditure proposals and quality targets. The Technical Advisor report was published on the Commerce Commission website on 16 May 2014.[3] The report provides a detailed review of Transpower's asset management systems and practices that underpin the RCP2 submission. The findings in the report include an assessment that Transpower's asset management framework is in accordance with good electricity industry practice, as follows:

> 5.2.4 Findings on the asset management framework
>
> 186 From our review of the asset management framework documentation and demonstrations of the systems and models in operation, we have reached the following conclusions:
>
> (a) The framework used by Transpower for developing E&D projects is logical and is in line with practices seen in equivalent transmission companies.
>
> (b) The use of asset lifecycle management for the development of R&R base capex projects and programmes is consistent with GEIP.
>
> (c) With on-going development and refinement, Transpower's asset lifecycle management practices can provide a useful window through which the state of individual asset fleets and the whole network can be viewed, including the sensitivity of asset health to changes in expenditure over time.

2.4 Review by the Office of the Auditor General

In September 2011, the Office of the Auditor General (OAG) published their report *"Transpower New Zealand: Managing risks to transmission assets"*.[4]

In late 2013 and early 2014, the OAG reviewed the progress that Transpower had made since the 2011 review. The following extracts are taken from their 2014 review:[5]

> 4.70 In our view, Transpower has been proactive in its efforts to improve grid asset and risk management since we published our 2011 report.
>
> 4.71 Transpower has set up a large number of initiatives that cover all elements of asset and risk management. Many of the initiatives are still in various stages of development. They are progressing on a measured path that, if continued, will meet best-practice asset management and deliver the long-term outcomes described in Transmission Tomorrow.
>
> 4.72 A particular strength is the asset management framework, including the comprehensive documentation that underpins it.
>
> 4.73 The asset and risk management initiatives have been used to prioritise future investment proposals, even though some have been acknowledged as "interim" measures.

[3] Commerce Commission, 2014: Technical Advisor Report on the Transpower New Zealand Ltd IPP Proposal for RCP2

[4] Office of the Auditor General, 2011: Transpower New Zealand Limited: Managing risks to transmission assets

[5] Office of the Auditor General, 2014: Following up on our 2011 performance audit of Transpower New Zealand Limited

2.5 Achievement of accreditation to PAS55:2008

In its submission of expenditure forecasts for the 2012-2015 period to the Commerce Commission in February 2011, Transpower made a commitment to work towards compliance with PAS55:2008 *Asset Management*.

In April 2012, Asset Management Consulting Ltd (AMCL) was engaged to carry out an initial assessment of Transpower's asset management practices against PAS55. This assessment identified a range of gaps. A programme of improvements was then launched to close the identified gaps. AMCL carried out a further gap assessment in November 2013, and this confirmed that significant progress had been made.

A formal certification process took place in June 2014, and Transpower obtained accreditation to PAS55:2008 in July 2014.

2.6 Optimisation and risk in asset management

Asset management is fundamentally a process and discipline that seeks to find an appropriate balance between costs, risks and performance.

The following extract is taken from PAS55-2:2008– p12:

> A key feature of good asset management strategy and plans is the optimisation of costs, risks and performance over short and long timeframes, in the face of conflicting stakeholder expectations. The processes of optimisation are critical, therefore, to the quality of the asset management strategy and the effectiveness and efficiency of asset management plans(s).

The remaining sections of this report examine the role of risk management in the optimisation of asset management strategies and plans, with a focus on planning and risk review in relation to Penrose.

3. SYSTEM PLANNING AND DEVELOPMENT

3.1 Annual planning process

Transpower follows a structured process for review of transmission system development needs, and publishes an Annual Planning report (APR). The APR represents our view of how the National Grid might be developed over the next 15 years to provide both reliability of supply and facilitate a competitive electricity market. To achieve this, the APR:

- presents a grid development plan, which includes possible transmission investments based on preliminary assessments [6], and
- aims to provide information to enable interested parties to:
  - understand the transmission network's ability to supply their needs
  - provide input into our transmission network development plans

[6] This plan does not include detailed analysis which occurs closer to the need date for investment. Nor does it imply that we have formed a view about a particular transmission investment, or that a transmission (versus a transmission alternative) investment is the most efficient solution.

- identify and evaluate alternative transmission network investments
- identify potentially preferred locations for connecting significant load (e.g. heavy industry)
- identify locations that may benefit from demand-side initiatives, and
- assess generation development opportunities, such as preferred locations and the ability of the transmission network to accommodate the proposed generation.

The latest Annual Planning Report 2014 is published on Transpower's website.[7]

3.2 Transmission investment framework

The publication of the APR enables stakeholders to review and comment on the analysis of transmission needs, and the range of potential transmission solutions that are identified.

Risk considerations are prime drivers of proposed investments in the grid – whether these are in the interconnected grid or in customer-specific connection assets. However, the framework for these investments varies, depending on whether the investment is in interconnection assets, or connection assets.

For investment in interconnection assets, the risk management considerations are that the investment is required to maintain the "n-1" security standard for those parts of the grid defined as the "core grid" in the Electricity Industry Participation Code. For the rest of the interconnected grid, investments must meet the economic test of highest positive net market benefit. The risk of alternative options, including the "do nothing" option, is typically evaluated in terms of reliability, which is expressed as expected value of unserved energy.

Investment proposals for the interconnected grid are reviewed and approved in accordance with processes defined by the Commerce Commission.

For investments in new or enhanced customer-specific connection assets, the customer chooses the investment but we are required to assess the proposed investment against other options to evaluate whether it is consistent with the Grid Reliability Standards (GRS) as defined in the Electricity Industry Participation Code. Investments in new or enhanced connection assets are subject to a bilateral customer investment contract.

The overall investment framework is summarised in the following table:

Investment type	Definition
Base Capex	Replacement and Refurbishment projects of any value, or Development projects forecast to cost less than: • $5 million in Regulatory Control Period 1 (RCP1), or • $20 million in Regulatory Control Period 2 (RCP2) These proposed projects are funded under a CC-approved approved Base Capex allowance.
Major Capex	These are individual investment proposals to enhance the Grid, which are submitted to the Commerce Commission for approval on a case by case basis. The cost threshold for individual enhancement project approval is $5 million in the current period (RCP1) and increases to $20 million for RCP2 (which begins April 2015). Each proposal must

7 Annual Planning Report: https://www.transpower.co.nz/resources/annual-planning-report-2014

	comply with the regulated Investment Test as prescribed in the Transpower Capital Expenditure Input Methodology Determination[8]
Customer-specific	Enhancement projects on assets specific to a customer or group of customers which are agreed and paid for under a customer investment contract between Transpower and the customer/group of customers.

3.3 Planning for replacement of existing assets

The condition and health of existing assets is assessed on a regular basis. Fleet strategies define the approach to condition assessment and replacement planning.

For evaluating investments in replacement of existing assets, risk is often expressed using the concepts of asset health and criticality, as proxies for the probability and consequence of asset failure. Fleet strategies are used to document the approach for individual classes of assets. Individual asset replacements are typically prioritised on a nationwide basis within programmes of work for the fleet of similar equipment, using asset health and criticality as a key input. Economic analysis is used to support the strategies for fleet replacement programmes, and aims to represent asset performance and safety risks in an economic framework.

Risk management considerations used in prioritising equipment replacement may include the risk of fire.

The replacement of existing assets is funded via the Base Capex allowance outlined in section 3.2 above.

An example of a significant asset replacement project that is justified by risk considerations is the planned replacement of the two 220 kV oil filled cables at Bream Bay substation. These cables are critical to the supply to the New Zealand refinery at Marsden Point. Provision has been made in the expenditure forecasts for the RCP2 period (1 July 2015 to 30 June 2020), for the replacement of these cables.

A further example of a risk-based replacement project is the work currently in progress at Penrose to replace the existing outdoor 33 kV switchyard with an indoor switchboard.

3.4 History of transmission development in Auckland since 1995

A separate supporting document has been prepared to provide an overview of the development of the Auckland transmission system since 1995.[9] It mainly focuses on the interconnected grid and the capacity and levels of security that the transmission system provides. However, the report also includes a specific focus on developments at Penrose substation.

In the period since 1995, there have been a wide range of investments in improving capacity and reliability of the transmission system supplying Auckland. The

[8] Commerce Commission, January 2012, Transpower Capital Expenditure Input Methodology Determination [2012] NZCC 2

[9] Auckland Regional Development, Transpower, November 2014

supporting document identifies more than 30 significant projects that have either re-inforced supply into the Auckland region, or increased capacity at individual grid exit points in the region.

Three of the major transmission projects are outlined below. The combined value of these three major projects is approximately $1.5 billion.

Otahuhu Diversity Project

This project provided a major redevelopment of the Otahuhu substation, resulting in a configuration that is appropriate for New Zealand's largest substation. The scope included reconfiguring lines to remove crossovers, physically separating two halves of the 220 kV switchyard, and building half of it in highly reliable Gas Insulated Switchgear. Circuits were diversified between the two switchyards so that a loss of one complete switchyard would not result in a total loss of supply to substations via Otahuhu.

NIGU project

The North Island Grid Upgrade (NIGU) project included a new 400 kV double-circuit transmission line (presently operated at 220 kV) between the generation-intensive central North Island, and Auckland's Pakuranga substation. Pakuranga was upgraded from a 110 kV to a 220 kV substation at the same time. This project created a major new point of supply into Auckland, diversifying away from the Otahuhu substation.

The NIGU project also relieved generation constraints, and allowed more expensive forms of generation such as coal and inefficient gas plants to reduce output, being replaced by renewable forms of energy available south of Auckland.

NAaN project

The North Auckland and Northland (Naan) project started at Pakuranga where the NIGU project finished. This included installing a 220 kV underground cable from Pakuranga to Penrose and on to Albany on the North Shore. Along with the existing 220 kV Henderson-Otahuhu overhead line, this forms a high-capacity transmission ring around Central Auckland.

The NAaN project includes connections to Vector's sub-transmission system at Hobson Street in the CBD, and at Wairau Road on the North Shore. This has created very secure, high-capacity electricity supplies to the CBD and North Shore areas.

3.5 History of development of the Penrose site

A brief report has been prepared that describes the development history of Penrose Substation, with a focus on the 33 kV supply and the assets most affected by the fire in the cable trench on 5 October 2014.[10]

[10] History of Penrose Substation, Transpower, November 2014

The report describes the history of Penrose from establishment in 1922. It outlines the initial establishment of the 110 kV switchyard, and the upgrade to 220 kV in the 1966 when the first 33 kV feeders from the site were established. About half of the outdoor 33 kV switchyard that we see today was built in 1966.

When the outdoor 33 kV switchyard was established, a cable trench was constructed running west to east across the 220 kV switchyard, to carry multiple 33 kV feeder cable circuits from the outdoor 33 kV switchyard to Gavin Street.

The report describes several stages of upgrade of the 33 kV supplies, including the installation of the T11 supply transformer and an indoor switchboard in 1999, taking the 33 kV supply capacity up to approximately 400 MVA.

4. SITE STRATEGIES AND PLANS

This section outlines the main asset management planning processes for sites.

4.1 Site strategies

We are developing strategies for all Transpower sites to provide strategic direction for their development and to bring together a range of substation information into a single concise document. Each document contains current site and asset information alongside development plans and customer initiated projects. The site strategies are being developed to identify future substation requirements and to highlight key issues to consider when developing and maintaining our assets. This will provide guidance when making investments at the site, enabling the co-ordination of work and the minimisation of project costs by ensuring work is not duplicated. The strategies align with Transpower's philosophy of adopting a "whole of life" cost approach for developing and managing our assets.

The site strategies are developed by collating site and asset information from internal Transpower sources and through site visits. A wide range of information informs the strategies including:

- Planned network development
- Planned asset replacement and refurbishment plans derived from fleet strategies
- Property considerations and constraints
- Environmental requirements and constraints
- Planned outage information
- High Impact Low Probability (HILP) studies
- Planned asset transfers

When draft site strategies are prepared, they are presented to affected customers for their input and feedback, before they are finalised.

The site strategy development programme commenced with the publication of a strategy for Islington substation in June 2012. As at November 2014, there are approved site strategy documents for 61 sites. We aim to prepare 20 new site strategy documents and review 10 existing site strategies in the current year, with a similar target for the following year.

A Transpower site strategy for Penrose substation was published in June 2012.[11] Many of the projects outlined in the document have been completed or are currently in progress.

Significant projects identified in the Penrose strategy that are currently in progress as at November 2014 include:

- The 220 kV bus is being extended to become a ring bus where the new section will be cable. The ring bus will provide improved resilience.
- The existing outdoor 33 kV switchyard is being replaced by an indoor switchroom, with indoor switchgear separated into fire segregated cells.

Risks identified in the Penrose site strategy include overhead earthwires crossing 220 kV busbars. Work has subsequently been completed to remove one critical earthwire, and options for other earthwires are currently under review.

The Penrose site strategy refers to the following statement, taken from Vector's published asset management plan 2013-2023:[12]

> The long-term plan is to reduce demand on the Penrose 33 kV bus through the establishment of new GXP's at Southdown and Newmarket. It is intended to phase out Penrose 22 kV either by transferring load to Penrose 33 kV, Southdown or Newmarket GXP's

4.2 Asset management plans

Asset Management Plans define the detailed activities that Transpower undertakes to deliver its asset management strategies and achieve its asset management objectives. The Asset Management Plans cover the complete asset lifecycle (planning, delivery, operation, maintenance and disposal). These plans can be development plans, site plans or specific asset plans and they would normally cover:

- intended tasks and actions
- resources that are required to implement these plans
- the expected (or required) timing of the works.

Developing grid asset management plans is necessarily iterative, as they reflect the optimisation and prioritisation that takes place in the integrated works planning and grid works planning processes as described in Transpower's Planning Lifecycle Strategy.[13] Asset Management Plans are reviewed and updated on an annual basis. The main outputs from the planning process are detailed schedules of forecast expenditure and deliverables.

[11] TP.TS 80.04 Site Development Strategy – Penrose Substation, June 2012

[12] Vector's Asset Management Plan 2013-2023

[13] TP.FG 01.01 Lifecycle Strategy - Planning, October 2013

4.3 Contingency preparedness

Asset management strategies and plans provide pro-active control of risk, and asset management activities are controlled through standards, procedures, alarms and monitoring, and competency and training. Asset management plans also include a robust approach to contingency preparedness.

Emergency contact details and call-out arrangements are maintained, and there are well established mobilisation processes, communications capabilities and escalation procedures for incident management.

Major failures of some items of substation equipment can potentially lead to extended periods of reduced security, and potentially to total interruption of service. Extended outage durations can occur if the damaged item of plant requires a long lead time for replacement. To mitigate the risks associated with long recovery times, Transpower holds a wide range of strategic spares, with the aim of providing a prompt response capability, even for failures of large items of equipment. The inventory of major strategic spares includes:

- Strategic spare power transformers, selected to provide flexible response capability for almost all in-service power transformers
- A strategic spare transportable switchroom, configured for operation at either 33 kV, 22 kV or 11 kV
- A mobile substation suitable for providing emergency response for small 110 kV substations
- Sets of unit spares for most outdoor equipment types, eg outdoor circuit breakers, instrument transformers

4.4 Routine operations and maintenance plans

Transpower's plans for operations and maintenance of sites are guided by a large number of standards, specifications, maintenance procedures and operating instructions. All of these documents are risk management controls, and many have relevance to fire risk mitigation.

Substation inspections are an important element in the operational control of risk. All substation sites are inspected monthly, and a detailed inspection and condition assessment of substations is completed annually.

In addition to basic inspections, specific preventive maintenance regimes are in place for all main items of substation equipment. These vary significantly, depending on the type, make and model of equipment. The preventive maintenance approach is intended to identify potential risks of failure, so that remedial measures can be implemented before failure occurs.

Many items of substation plant also have built-in alarms and monitoring systems to detect and report abnormal conditions. Alarms are relayed to a continuously attended National Grid Operating Centre, and are then assessed and prioritised for the required response. Transpower maintains 24 hour call-out maintenance response capability for all sites.

Substation sites are all provided with security fencing and access control systems, to prevent unauthorised entry. Access control systems are monitored from a remote location, and security guard call-out arrangements are in place to respond to security alarms.

There are minimum competency requirements for persons to be issued with access authority. There are defined competency standards for various classes of work, and contractual requirements for workers to be competent before undertaking work on Transpower substation assets. Transpower provides structured training in core skills that are needed for substation maintenance.

Safety hazards and risks are given high priority. Hazards at sites are identified and registered on hazard boards displayed at prominent locations in the substation control rooms. The information on these hazard boards is now being supplemented by the establishment of a register of safety hazards in the asset management information system (Maximo). The register of hazards also includes a set of standard precautions for each hazard.

5. DESIGN FOR FIRE RISK MITIGATION

5.1 Introduction

The planning and delivery lifecycles within the asset management system include the stages of concept design, detailed design, specification and procurement for new and replacement assets. In all these stages, there are balanced trade-offs made between cost, risk and performance. Designs take into account international good practice in the mitigation of risk, and specifically include NZ industry safety standards and codes.

Transpower has an extensive suite of intellectual property embodied in its technical policies, design standards, standard design packages and procurement specifications.

Where practicable, Transpower uses standard design approaches, to achieve efficiencies, and to provide a basis for continual improvement, based on learnings from recent implementations of the standard design

A typical example of a design standard that incorporates trade-offs between cost, risk and performance is TP DS 62.*01 Clearances and conductor spacings – and a safe access for a.c. switchyards*.

5.2 Substation fire risk mitigation standard

One of the important inputs to substation project development and design is the need to mitigate fire risks. Fire risk mitigations have been incorporated into substation designs over many years. Common practices include:

- Provision of smoke detectors in control rooms, relay rooms, switchgear rooms and cable basements, with fire alarm signalling to control centres and directly to NZ Fire Service from some sites

- Physical separation and fire rated barriers between indoor high voltage switchgear and transmission control and protection equipment
- Physical separation between high voltage power cables and control and instrumentation cables
- Provision of oil containment bunds around large power transformers, and provision of drainage and oil interception facilities
- Fitting of smoke stop barriers between cable basements and control/relay panels and rooms
- Specification of control and instrumentation cables with flame-retardant sheaths for use in critical installations such as the HVDC converter stations
- Provision of fire suppression systems in critical facilities. Examples include water deluge systems on HVDC converter transformers and the Pole 2 valve halls at Haywards and Benmore, and in the 220 kV cable tunnel and vertical shaft at Rangipo Power Station

The Transpower standard TP DS 61.06 *Substation fire mitigation* provides guidance for project designers, but also provides guidance for mitigation of fire risks through good practice on-going operations and occupancy of sites. Retrofitting of fire risk mitigations to legacy sites is also addressed.

One of the most important elements of the fire risk mitigation standard is the prioritisation of sites based on substation criticality. A multi-criteria approach has been taken to establishing a ranking of substations, for the purposes of categorisation into 5 bands. The standard specifies specific fire risk mitigation approaches for various categories of asset criticality.

The May 2014 issue of TP DS 61.06 includes policy intentions for retrofitting hypoxic air fire prevention systems in the control and relay rooms of substations in the two top bands of criticality. The standard also indicates the provision of automatic fire suppression in cable basements and tunnels for substations in the top three bands of criticality.

Retrofitting fire risk mitigations can be costly, and implementation must be phased over time.

However, fire risk mitigations have already been retrofitted at many sites. Examples include the provision of bunds and firewalls around existing power transformers, and the fitting of arc flash detection in a number of legacy indoor switchboard installations.

Provision has been made in the expenditure forecasts for the RCP2 period 2015-2020 for installation of the first tranche of hypoxic air installations at five high criticality sites.

5.3 Fire risk mitigations at Penrose

The major power transformers at Penrose are all installed within bunded areas, to minimise the risk of spread of oil and fire in the event of a severe failure. The recent installation of the Penrose power transformer T7 also includes firewalls. Other significant fire risk mitigations include the establishment of a second control/relay room to provide a more robust environment for future control and protection, and to provide diversity from the existing facility.

There is a project currently in progress for conversion of the existing outdoor 33 kV switchyard to an indoor switchroom. This will include multiple bus sections in fire rated compartments.

Following a review of High Impact Low Probability (HILP) risks conducted at the Penrose site in 2013 (see section 6.4 below), additional fire risk mitigations are proposed, including:

- additional fire walls between the 220/33 kV power transformers
- improvements to firewalls surrounding 33/22 kV transformers T21, T22, T23
- upgrade fire prevention and protection in the existing control/relay room

6. SITE RISK REVIEW PROCESSES

6.1 Introduction

The preceding sections of this report outlined the pro-active management of risk through system and site planning, and in the design of installations. Risk management also requires effective processes for the review of existing risks.

This section describes a range of risk review processes that contribute to the management of asset risk at individual sites, by identifying risks in the existing installations that may warrant mitigation. Some opportunities are identified for integration and improvement in existing processes for the review of site risk.

6.2 Scheduled inspections and condition assessment

Substation maintenance service providers undertake routine monthly inspections, including a basic visual inspection covering all substation equipment, including buildings, grounds and security fences.

More detailed inspections and surveys are undertaken on an annual basis, including some operational checks. Maintenance service providers are currently required to provide a written report based on the annual inspections, outlining the condition of all equipment on site.

In addition, all main items of equipment have scheduled preventive maintenance, including servicing and diagnostic testing. The intervals between preventive maintenance vary by type of asset.

Defects identified during inspections or preventive maintenance are entered into Transpower's asset management information system (Maximo) for review, reporting and scheduling of corrective actions.

Inspections, servicing, testing and reporting processes are an important element of site risk management, and are intended to highlight emerging issues of concern.

The maintenance service provider's annual condition assessment reports for Penrose substation may identify a range of issues that require attention, ranging from significant corrosion on a range of outdoor equipment, to legacy items that do not comply with current standards. These issues then get prioritised for attention within the maintenance and works planning processes.

The most recent annual condition assessment report for Penrose is dated July 2014.[14] This report deals mainly with the substation primary equipment, although there is some additional content related to protection and communications equipment. The scope is limited to assets owned by Transpower at the Penrose site.

6.3 Reliability engineering reviews

In addition to the regular reviews of asset condition undertaken by substation maintenance service providers, a small team of Transpower Reliability Engineers work with maintenance managers and service providers to review the condition and performance of substation assets. This work typically leads to proposals for preventive actions to mitigate identified risks. These proposals are entered into tactical asset management plans for the site.

6.4 High impact low probability event reviews

In 2011 Transpower commenced a programme of studies of High Impact, Low Probability (HILP) event risks at substations. The programme commenced with a review of the Islington site. This initial study was a prototype, and was used to develop the methodology. It was carried out as part of a wider review of security of supply to the Upper South Island.

As at November 2014, HILP risk studies have been conducted at nine sites:

- Islington
- Bunnythorpe
- Penrose
- Central Park
- Wilton
- Kaiwharawhara
- Huntly
- Ashburton
- Twizel

The current planning intention is to undertake HILP risk reviews at three sites each year. Transpower's approach to High Impact Low Probability (HILP) risk assessment is documented in a paper by Transpower authors, entitled "*Transmission planning and unexpected events*". [15] This paper was presented at an IEEE sponsored international conference on Probabilistic Methods Applied to Power Systems (PMAPS) in 2014.

[14] Penrose Annual Condition Assessment Report 2014

[15] S Todd, G Ancell, *Transmission Planning and unexpected events*, PMAPS 2014

The paper introduces an economic framework that can be used by transmission asset planners to frame an economic justification of proposals to mitigate identified HILP risk exposures, and also to demonstrate when it is no longer economic to do so. In this way grid-wide mitigation strategies can be rationally proposed and defended by planners, and HILP event risk exposures understood to the extent that is practicable.

A HILP risk study for Penrose substation was undertaken in 2013, using the methodology outlined in the PMAPS conference paper.

Transpower engaged Marsh as independent risk advisors to undertake some aspects of the HILP risk study work for the Penrose site. The scope of risks considered in the Marsh report dated April 2013 included:

- Earthquake
- Liquefaction/subsidence
- Volcanic activity
- Tsunami
- Fire/explosion (Building/Network Plant)
- Impacts
- Flood
- Sabotage
- Severe Weather (including tornado)
- Exposure from/to 3rd Parties

The Marsh report considered a range of fire risks, and recommended some additional fire risk mitigations. The report recommended the replacement of timber trench covers in Transpower cable trenches in the 220 kV switchyard. However, the report did not specifically identify the Vector cable trough as a source of risk.

The final HILP report for Penrose substation was published in June 2013. The main findings of this report are as follows: [16]

- Once the NAAN project is completed and Vector carry out their planned 110 kV reinforcement from Hobson St, the Auckland CBD supply security resilience will be significantly improved with Vector/Liverpool St being able to be supplied from the north as well as Penrose and a backup 110 kV cable to Mt Roskill.
- The supply to Penrose 22 kV and 33 kV is susceptible to a number of issues, namely existing control building fire and earthquake affecting the 22 kV and 33 kV indoor switchboards, and transformer fire in the 220 kV switchyard. Firewall installation and existing control building earthquake mitigation works appear justified and fire detection and suppression in the existing building is likely to be. All of these projects need to be advanced.
- The Low Tension AC network needs to be fully reviewed similar to the review recently carried out at Islington to understand future development needs and existing condition.
- The Overhead Earth Wires in evidence over the 220 kV switchyard structure need to be investigated further to see if there is a case for removing them or changing the design.

[16] NP573: Penrose Substation High Impact Low Probability Event Study, Transpower, June 2013

Since the completion of the HILP study in June 2013, there have been a number of significant developments:

- The most recent engineering assessment of the seismic strength of the original control building indicates that a strengthening project is viable, and can provide at least another 20 years life extension for the building. Work is expected to commence on site in February 2015.
- Now that a decision has been taken to retain and strengthen the building, the retrofitting of enhanced fire protection can be considered, in accordance with the substation fire risk mitigation standard discussed in section 6.5.
- Installation of fire walls around power transformers is now in planning. The T7 transformer already has firewalls. Additional firewalls will be installed between T9, T10 and T11 when the existing T10 inter-connecting transformer is replaced. It is not practical to install firewalls around the existing T8 power transformer, but this is currently considered to be an acceptable risk for the short-medium term. The longer term plan is for a replacement for T8 to be connected to Bus D. This will provide fire separation and a fire wall, between T7 and T9.
- A review of the local service supply system at Penrose is planned, and this will follow the process used for a similar review at Islington.
- The overhead earthwires over the 220 kV bus have been reviewed, and one has already been removed. Work is in progress at present to finalise the review of lightning protection at Penrose, and specify alternative lightning protection where appropriate.

6.5 Substation fire risk reviews

The Transpower standard TP DS 61.06 *Substation fire mitigation* is described in section 5.2 above.

Issue 3 of the standard, dated May 2014, outlines an intention to undertake a further round of reviews of all existing substation sites in the top three bands of criticality, focussing on fire risks. Penrose substation is classified in the second band of criticality, (in Appendix A2 of the standard).

This further round of fire risk reviews is currently at the planning stage.

6.6 Customer assets on Transpower land

The interconnected nature of electricity networks requires that distribution network customers own feeder connection assets located on Transpower land.

The usual ownership boundary between the transmission and distribution system is at a feeder circuit breaker or disconnector. From that point, the feeder circuit is owned by the distribution network company. Feeder circuits may be overhead, or cabled, depending on the switchgear and busbar arrangements. These distribution feeder circuits must necessarily traverse the transmission substation site.

The distribution network company needs assurance that their assets may be installed and can remain on Transpower land. In return, Transpower needs to know about the distribution company assets, and to be assured that they do not present unacceptable risks to the safety of people working in the substation, or to the reliability of the grid.

In the past, there have been a variety of practices adopted for agreeing to customer assets on Transpower land. The various historic practices are outlined in a supporting document: “Access and Occupancy”, including details of existing occupancy arrangements for Penrose Substation.[17]

In 2008, Access and Occupation schedules were included in the Benchmark Transmission Agreement that is now incorporated in the Electricity Industry Participation Code. The Connections Contract signed by Vector in 2000 still applies at Penrose, and this has a similar Access and Occupation Schedule to the current agreements.

The Access and Occupation schedule includes requirements for the customer to comply with Transpower’s safety and site security standards, and to operate and maintain their facilities in accordance with good electricity industry practice. Customers must also seek Transpower’s consent for upgrades or improvements to the facilities, or the establishment of new equipment outside the documented facilities area.

The most recent version of the Access and Occupation schedule for Penrose, effective 1 April 2008, includes two 110 kV feeders, eighteen 33 kV feeders, and fourteen 22 kV feeders, together with a ripple control and relay building, and protection and metering equipment. The schedule does not include the 11 kV cables that were also present in the cable trench where the fire occurred.

Prior to the incident at Penrose, Transpower had recognised the need for improvement in the quality of information held about customer owned assets on Transpower land. Better information is needed to reduce the safety risks that can be associated with unidentified live cables, particularly buried cables. A programme of work was already planned to review access and occupation schedules with customers, and improve the quality of the information held by Transpower.

Efficiencies can be gained by co-ordinating the review of access and occupation arrangements with some of the other systematic reviews of site risk.

6.7 Connection asset risk reviews

In the period 2009 to 2013, Transpower undertook a range of site reviews in conjunction with representatives of the customers connected at particular sites. The purpose of these “Connection asset risk reviews” was to identify risks and issues that could affect performance of assets at grid exit points.

The initiative was developed in response to several Transpower asset failures leading to unexpectedly large losses of supply and unacceptable impacts on

[17] Access and Occupancy, Transpower, November 2014

consumers. These failures highlighted a need for improved risk management at the grid connection interface.

A paper describing the Connection Risk Review process was presented at the EEA Annual Conference in June 2010. [18] The paper reports on the experience of conducting risk reviews jointly with customers at 20 sites. The conclusions presented in the paper are as follows:

> The Connection Risk Review process has already helped identify significant issues with the present design, configuration, condition and performance of connection assets. The process has enabled improved communication between Transpower and the customer that will lead to improvements in risk management and co-ordinated asset management planning at the grid interface.

The Connection Risk Review process for Penrose did not identify any issues relevant to the fire that occurred on 5 October 2014.

Nevertheless, the development of the process and its application at a considerable number of Transpower sites has been a useful learning experience. It provides a sound basis for improving our processes for systematic review of site risks.

6.8 Corporate risk management system

Transpower operates a risk management system that supports periodic reviews of enterprise risk. The process is distributed and multi-layered. Risk registers are maintained by a diverse range of business groups. Risks from these separate registers are assessed and aggregated into divisional registers. These aggregated risk registers are reviewed to prepare listings of top level corporate risks for consideration by management risk committees and the Transpower Board.

A paper describing Transpower's asset risk management process was presented at the EEA Annual Conference in June 2014.[19] The paper reports that Transpower has established, and is embedding, an Asset Risk Management Policy and framework which directly aligns with its Grid Asset Management and Corporate Risk Management Policies and frameworks.

In addition to establishing a formal Asset Risk Management Policy and process, we have also established a suite of tools including:

- Asset Criticality,
- Asset Health Indices,
- Tactical Asset Management Plans and
- a Health, Safety and Environmental add-on to our Asset Management Information System

These tools actively support and inform our understanding of its asset risks and associated asset management decisions. These improvements are aimed at providing better organisation-wide insights for enabling better asset management

[18] H Chhima and M Clark, *Connection Risk Review Process*, EEA Conference, June 2010
[19] P Griffiths and B Stimson, *Asset Risk Management – a key asset management tool*, EEA Conference, June 2014

decisions and facilitating continuous improvement in the way grid assets are managed.

6.8.1 Bottom up risk identification, assessment and aggregation

Detailed risk registers are prepared by various teams within Transpower as part of a “bottom-up” approach to grid asset risk identification and management. These “bottom-up” risk registers are aggregated to Divisional risk registers that are in turn consolidated into the Corporate Risk Register.

The bottom up process typically generates a large number of risk statements, but not all of these warrant escalation. Priority for further risk analysis, including documenting risk controls and treatments, is based on an initial risk assessment.

This initial risk assessment is used as the main means of selecting risks for escalation from lower level team-based register to higher level divisional risk registers. In general, priority for escalation and further risk analysis is given to risks assessed with inherent risk levels of “High” or “Extreme”. In some cases, risks from separate teams are aggregated where there are overlaps or duplications.

The aggregated Grid Performance risk register is presented regularly to meetings of the Grid Performance leadership team, and top risks are selected. The top risks from Grid Performance, together with those from other Transpower divisions, are communicated to the Transpower staff Risk Committee. This is a cross Divisional team. They are responsible for the compilation of the Corporate Risk Register. The Transpower Board regularly reviews the top risks in the Corporate Risk Register.

It is important to recognise that the bottom up risk identification process is a team-based process that invites participants to imagine what might possibly occur, and to consider the potential consequences and likelihood. The outcome of this process depends on the skills, experience and judgement of the participants.

Despite the benefits of drawing upon a broad base of knowledge and experience to identify risks within a bottom up risk identification process, it is widely recognised that it can still be difficult to identify rare and unusual modes of failure. Even where such risks are identified, it can be difficult to assess their severity because of the lack of historic data to provide guidance about likelihood.

6.8.2 Risk statements relevant to the Penrose incident

At the time of the Penrose cable fire, the various risk registers contained several risk statements that have some relationship to the event that occurred. The most relevant of these risk statements are:

Source	**Short title**	**Description**
Grid Performance -Northern North Island – ref NNI-23	Failure of connected customer equipment (TP site)	Failure of equipment (eg cables and joints) owned by connected customer on Transpower site causes safety hazard and fire/explosion damage to critical Transpower assets leading to loss of supply.
Grid Performance	Fire damage	Switchgear explosion, cable fire or other

(aggregated register) - ref NECI 16		ignition source in substation building causes major damage to network equipment resulting in extended loss of supply.

The risk statement ref NNI-23, as at October 2014, was a product of the bottom-up risk identification process outlined above. The risk statement was developed by the team in the Transpower Auckland office who are responsible for the management of grid maintenance in the Northern North Island region. The risk statement ref NNI-23 was first entered into the team risk register on 6 May 2014. It is a generic risk statement, applying to all substations where customers are connected. A preliminary risk assessment was undertaken, scoring this risk as “Medium” risk level, before controls (i.e. the inherent risk level). The risk level scoring was based on the Transpower risk assessment matrix.

The rationale for the initial team-based assessment of this risk is not recorded. However, the team would have been aware that failure of customer assets on Transpower land is an unusual event, and (at that time), there were no previous instances of severe damage to Transpower assets from this cause. The risk assessment of “Medium” severity is consistent with these understandings, and with the Transpower risk assessment matrix.

In general, priority for further risk analysis was given to risks assessed with inherent risk levels of “High” or “Extreme”. As a consequence, risk controls and treatments for the risk statement NNI-23 had not been documented as at October 2014, and this risk had not been escalated to the aggregated Grid Performance risk register.

The risk statement ref NECI 16, as listed above, formed part of the aggregated risk register for the Grid Performance division, as at October 2014. This risk statement includes the potential for cable fire, but is less relevant to the Penrose incident because it relates to substation buildings, rather than an outdoor cable trench. The register shows that this risk was assessed with an inherent risk level of “Extreme” and a residual risk level (after controls) of “Medium”.

A range of existing risk controls were identified for this risk that largely focus on substation building fire prevention, detection and protection.

6.9 Enhancement of risk identification and analysis process

Prior to the Penrose cable fire incident, Transpower had recognised that the current risk register process was difficult to manage and maintain, and required improvement.

An independent external review of the formal risk management process was undertaken in May 2014. The review recommended the implementation of a “bow-tie” approach to risk management, as a way of improving engagement, getting better quality understanding of risks and controls, and as a basis for semi-quantitative risk assessment.

The bow-tie approach is illustrated in Figure 2 below.

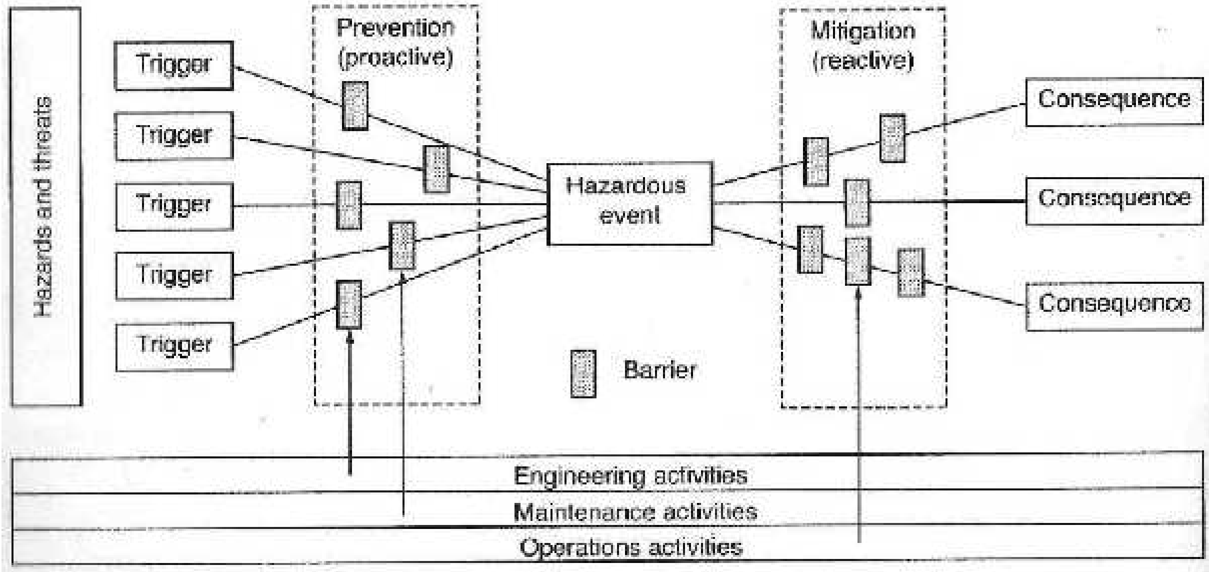

Figure 2 Bow-tie risk illustration

A proposal to implement the bow-tie methodology has been approved, and implementation is expected to commence in 2015.

A further opportunity for improvement is in the integration of site-based risk identification and management processes. Transpower periodically undertakes site-based reviews of design compliance, in such diverse areas as lightning protection, insulation co-ordination, substation earthing, oil containment and fire protection. These reviews are all carried out to identify risk and to determine whether risk mitigation work may be needed within the planning horizon.

There are opportunities for efficiencies and overall improvement in asset management planning from achieving greater integration between these separate strands of risk management activity. Work is already underway to improve the integration of site risk review processes.

7. REVIEW AND LEARNING FROM INCIDENTS

Learning from incidents is an essential element of continuous improvement in asset management.

As part of its overall asset management approach, Transpower operates multi-level processes for incident capture, recording, analysis, assessment, and reporting. These processes are essential for identification of risk, and the initiation of corrective actions.

These processes commence with the capture of incident data, either by field personnel, or by grid operators, depending on the nature of the incident.

A daily operations meeting provides an initial review of the preceding days grid events. All forced and fault outages of grid equipment are captured and analysed for the purposes of understanding the performance of the grid. A diverse range of reports are then prepared from the analysed data. These reports inform asset management decision making and are also used for providing transparency for stakeholders about the performance of the network.

Incidents involving safety, human factors or the management of contracts are analysed on a local or regional basis, unless they identify significant system-wide issues, when they may be escalated to a higher level management forum.

Events of national significance, either in terms of their impact, or their implications, are investigated and reported to a forum of senior managers. For events of the highest level severity, independent investigators may be engaged, and may be required to report directly to the Chief Executive.

These multi-level incident investigation processes generate recommendations for corrective and preventive actions that will improve future performance.

One example of learning from previous incidents is the enhancement of Transpower's fire risk mitigation policy following explosions and fires in indoor switchboards at Otahuhu in July 2007, and at Westport in October 2007. The design requirements for new indoor switchboard installations now include splitting indoor switchboards into fire segregated sections.