NEW ZEALAND POWER FAILURES

LESSONS TO BE LEARNT

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engineering new zealand
te ao rangahau

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This document summarises the webinar by Daniel Müller CMEngNZ and Geoff Hunt DistFEngNZ.

Daniel is an electrical engineer and a committee member of the Electrical Engineering Group and past president of the Society for Safety Engineering.

Geoff is also a member of the Electrical Engineering Group and a Board Member of Engineering New Zealand. He has many years of experience in the electricity industry in New Zealand, including 27 years in CEO positions and 'coming up' with the temporary solutions for the 1998 Auckland Power failure.

At the time of the failure Geoff was managing Alstom – the largest service provider to Transpower for transmission line and substation maintenance and construction, and operation of the regional control centre. Geoff was responsible for developing the response to the event.

1: INTRODUCTION

We are very dependent on electrical power in our daily lives. And if we lose power, even for a day or two, it can severely impact us.

And as we approach a carbon-zero future, we are going to be even more reliant on electric power, for example transportation and heating processes.

New Zealand has had some significant power failures. These failures and our response to these, provide lessons that we can build into our designs and systems in the future, so we don't repeat mistakes.

Substation fire. Source: Bruce Mills

2: SIGNIFICANT POWER FAILURES

New Zealand has had some significant power failures which have especially affected our large cities. This section looks at these, starting with 1998 Auckland CBD power failure.

1998 AUCKLAND CBD POWER FAILURE

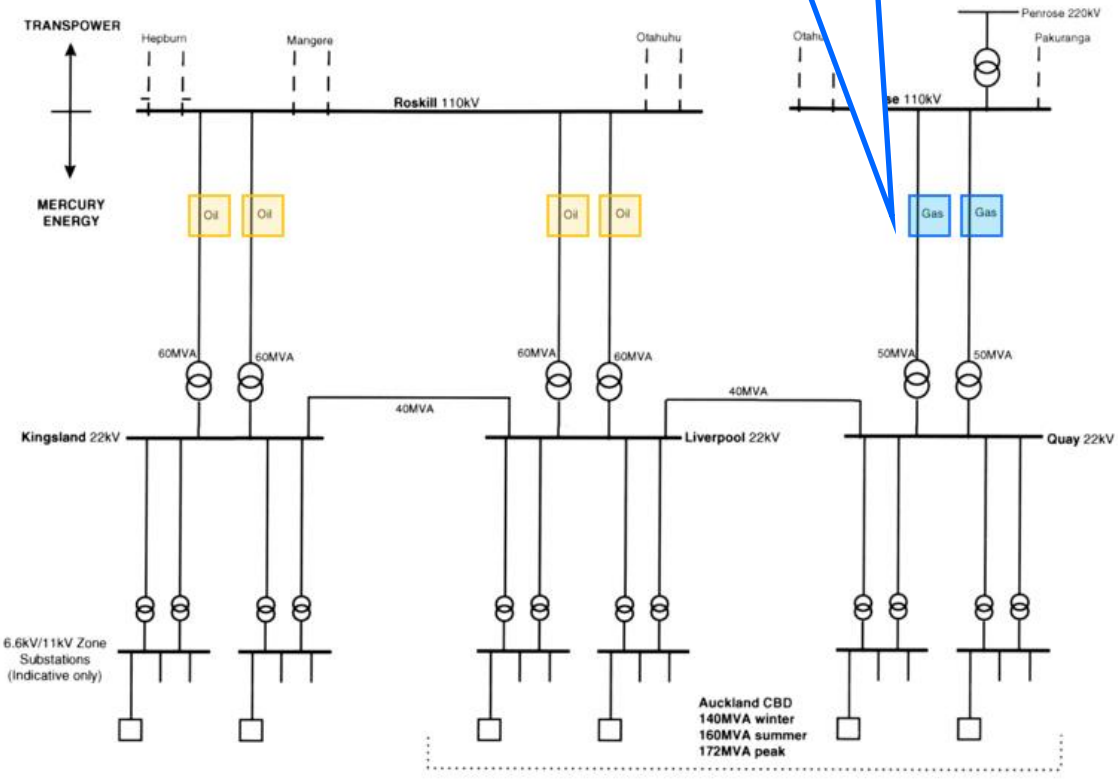
In 1998 the 110kV cables supplying the CBD substations failed, resulting in a five-week catastrophic power outage in the Auckland CBD.

Auckland CBD power system in 1997/1998

Let's start by looking at the power system itself. The diagrams following show the network supplying power by Transpower to Mercury Energy's Roskill and Penrose substations and then to the Auckland CBD.

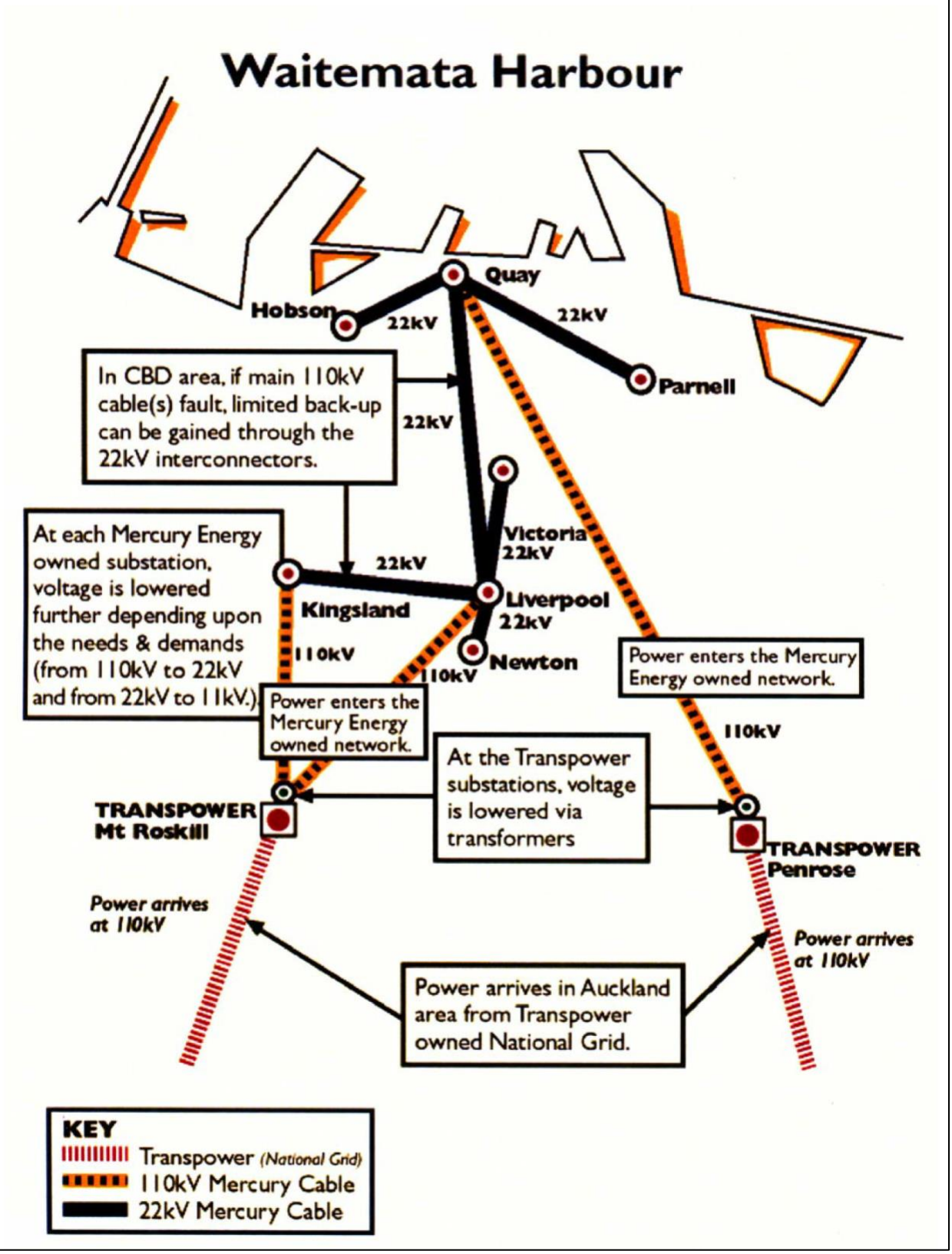
Note the oil and gas cables which supply the CBD, especially Liverpool and Quay. These are the cables which should have been OK, but that failed.

Figure 3.7 Power Supply to Auckland CBD and Fringe Areas



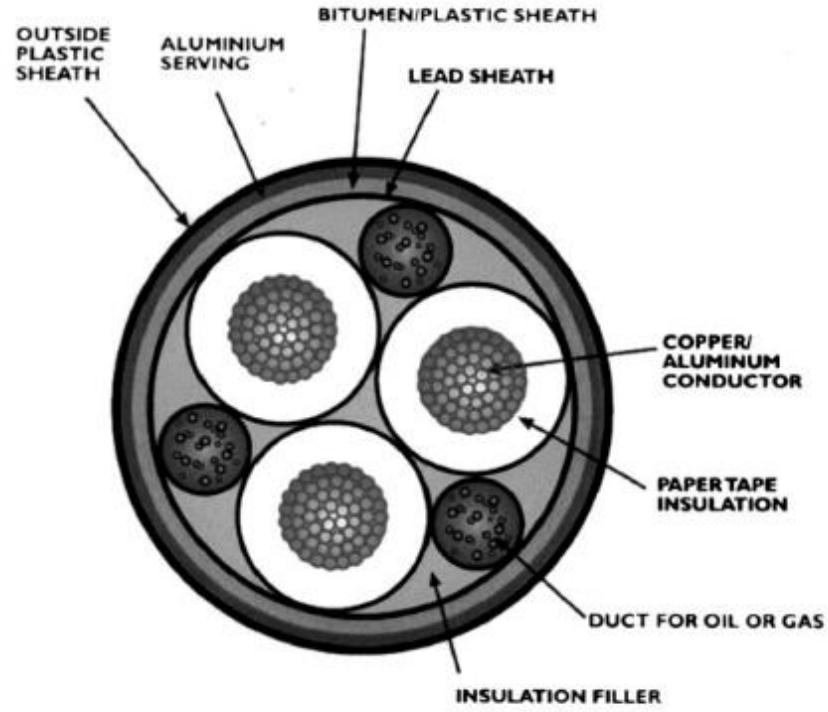
Source: Mercury Energy Ltd, 1998.

Figure 3.6 Mercury Energy Ltd Network 1997/98



Gas filled and oil filled cables are routinely used for high voltage electricity transmission. Reliable operation requires careful installation to ensure there is no excessive build up of heat in the cable. Excessive heat build up causes expansion and may result in the mechanical failure at the joints.

Figure 4.1 Typical Gas or Oil Cable Cross Section

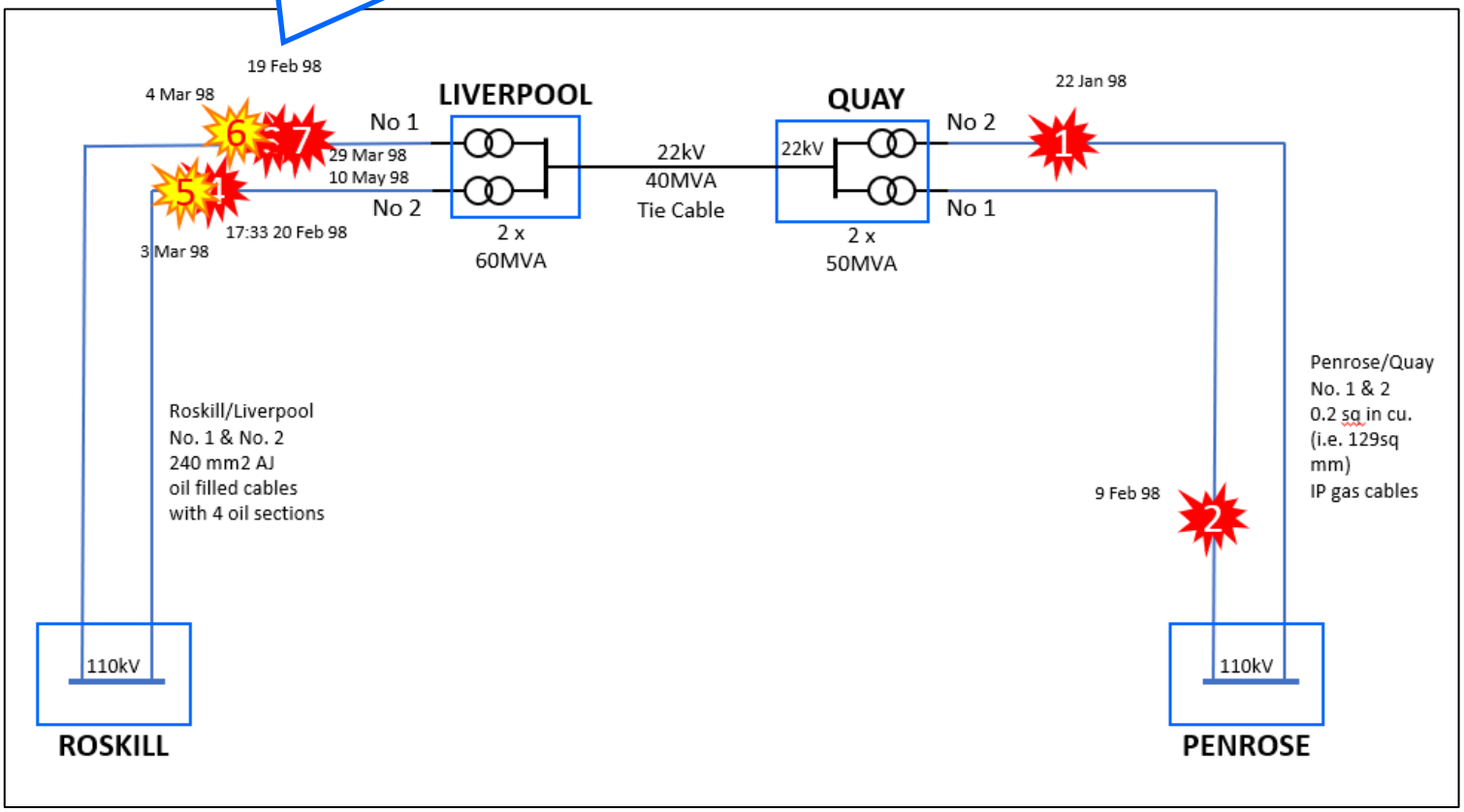


Source: Mercury Energy Ltd, 1998.

What happened?

In Auckland, it had been a hot dry summer, and the cables were carrying heavy electricity loads. The cables progressively failed over a number of days. The actual failure mode was thermal expansion leading to mechanical failure at the joints.

This diagram shows the cables on the Mercury Energy network and the cables that progressively failed over a number of days. There were attempts made to repair 5 and 6, but the recovery was short lived.



Learnings

The subsequent enquiry found that among other things:

- some of the cables had not been properly installed
- a gas leak had never been resolved
- there was no asset management plan for the cables
- the maintenance requirements were poorly specified, and
- the risk of failure was not understood at any level (and this was possibly why the planned cable tunnel from Penrose to the CBD had not made it to the board for approval).

This was an engineering failure on many levels!

Response to the event

Alstom – the largest service provider to Transpower was involved in the response to the power failure on a number of levels.

On Friday evening 20 February 1998, Transpower's Regional Control Centre Operator, advised Geoff Hunt (who was managing Alstom) that the last cable feeding the CBD had failed.

> *"Mr Hunt, this is the Transpower Otahuhu Area Control Centre. The last Mercury cable feeding the CBD has just failed……. We have a civil emergency"*

Initially Geoff thought it would take all night for Mercury to get some of the cables back into service. But early the next day he realised that there was a high risk that the cables would not be reliable and that a Plan B was required.

Using a road map, Geoff plotted out Plan B – a route for a temporary 110kV overhead line from Penrose to the Quay St substation and got the support from the Mercury CEO and the Transpower CEO for this temporary line.

The route for a temporary 110kV line from Penrose to the Quay St substation in the CBD.

A large team was assembled from around the country in Auckland. A fixed price for a 10-week build was provided to Mercury. Transpower provided support by delaying projects and supplying much of the hardware required.

Mercury engineers were initially confident that they had cable repairs in hand and were not interested in the plan, but the situation was critical, and the solution to build a temporary transmission line was approved 4 days later after intervention by the Minister and Transpower.

About a week later Mercury acknowledged that restoration of power to the CBD was at least 8 weeks away. The temporary transmission line was now on the critical path! (In fact, the work was completed in 18 days including a 1.2km T off to the Liverpool St substation, and some of the cables never returned to service.)

How do you recover from a failure of this size?

The plan to build the new transmission line was targeted to be completed in 21 days. Some of the key aspects of this crisis response were as follows.

1. Bring in the best organisations you can find. Beca, Hawkins and Alstom staff shifted into Alstom's construction base so that all the staff could readily communicate.
    - Beca was subcontracted as the designer.
    - The civil work and pole erection was subcontracted to Hawkins, who had the challenge of, amongst other things, sourcing all the mobile cranes and other plant required.
    - Alstom retained all the conductor stringing, and substation work – to convert the transformer bushings from cable to overhead line and innovate to build an open-wire high voltage line through an unused rail tunnel (a world first). They also had overall project management, scaling up to work across a 11km work front with a daily $500,000 spend with the goal to restore power.
2. Create an environment supporting trust and communication was critical for engineers across the various organisations. Relationships in Wellington were also critical, for example, to help get trains stopped when necessary.
3. Innovate on the fly.

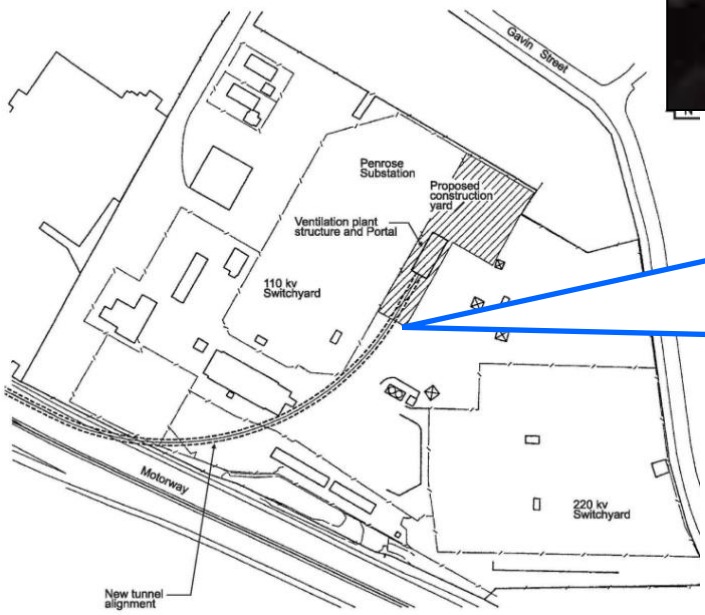
The temporary solution was to a build an open-wire 110 kV transmission line through a disused rail tunnel.

It turns out to be the only place that this has been done anywhere in the world!

Long term solution – Vector tunnel

The long-term solution was to build the tunnel from Penrose to Hobson Street.

That tunnel would carry cables for Transpower, Vector and telco providers, become an important infrastructure for Auckland, and increase the security of the network.

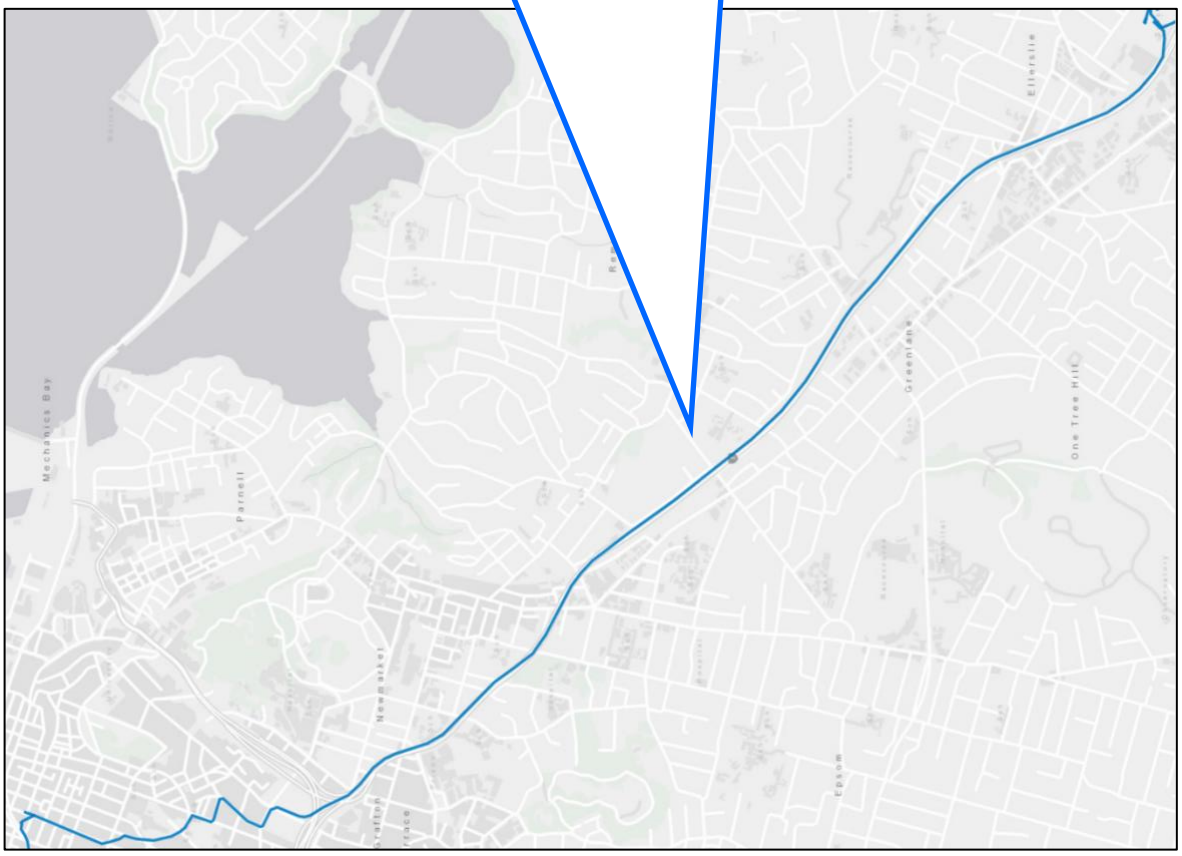


The dotted line shows the tunnel coming out of the Penrose substation and going underneath the motorway.

The tunnel comes out of the Penrose substation and heads under the motorway.

To access the tunnel there is a vertical shaft at the Penrose substation.

The Vector tunnel is shown by the blue line in this diagram.



2006 AUCKLAND

Eight years later, in June 2006, it was the turn of another part of Auckland to lose power.

What happened

Ageing infrastructure and the weather were again to blame. But this time, rather than a complex, multi-layered cable, it was a ridiculously simple fault.

At Transpower's Otahuhu substation, two D-shaped connector shackles broke in a 90km/h wind, allowing the wires to fall and make contact with 220kV and 110kV conductors.

This caused a six-hour power outage. 230,000 customers were affected including:

- rail disruptions
- radio transmitters had to be switched off
- partial hospital closures and postponement of procedures.

Learnings

This incident highlights the importance of maintenance, and the impact of not addressing even minor maintenance issues, such as replacing $25 shackles.

It also highlights the importance of having an accountability model where everyone, including board members, managers, and supervisors, understand and support the appropriate delegation of accountability for maintenance to those close to the equipment.

2009 AUCKLAND AND NORTH AUCKLAND

In October 2009 Northland and North Auckland lost power.

What happened

A forklift truck carrying a container struck a 220 kV transmission line. It was the only power line working at the time, as the other was undergoing maintenance.

This incident caused:

- a two-and-a-half-hour power outage to northern Auckland
- a four-to-five-hour outage to Northland.
- the temporary closure of the Marsden Point oil refinery (and the loss of $100,000s to the refinery)

Overall, 280,000 people were affected.

Learnings

This incident highlights the risk of vehicles travelling under lines. With containers on a forklift truck stacked high, there is a very high risk of a significant incident. All the neighbours along the transmission line should have been informed of the scheduled service of one of the feeders and alerted to the increased vunerability of the power supply which was relying in the sole operational feeder.

2011 CANTERBURY EARTHQUAKE

The 2011 Canterbury earthquake demonstrated the major effect a natural occurrence, like an earthquake, can have on an electricity supply and its infrastructure.

What happened

Massive damage was incurred to the power infrastructure across Christchurch.

- Fifty percent of the 66 kV cables were (damaged (30 km out of a total of 60 km), including underground.
- Four of 314 substations were severely damaged
- Fifteen percent of 11 kV cables were damaged (330 km out of a total of 2,200 km)
- Thousands of faults were identified
- Some damage to local substations (11kV/400 V) such as the Sumner substation.
- Some damage (cracked insulators and poles affected by liquefaction)
- One percent of LV cables were damaged
- Electrical system in badly damaged buildings
- Administration building including Control Centre badly damaged.

Note: the following maps, images and information show the extent of the damage. These are from Andrew Massie & Neville R. Watson, IMPACT OF THE CHRISTCHURCH EARTHQUAKES ON THE ELECTRICAL POWER SYSTEM INFRASTRUCTURE

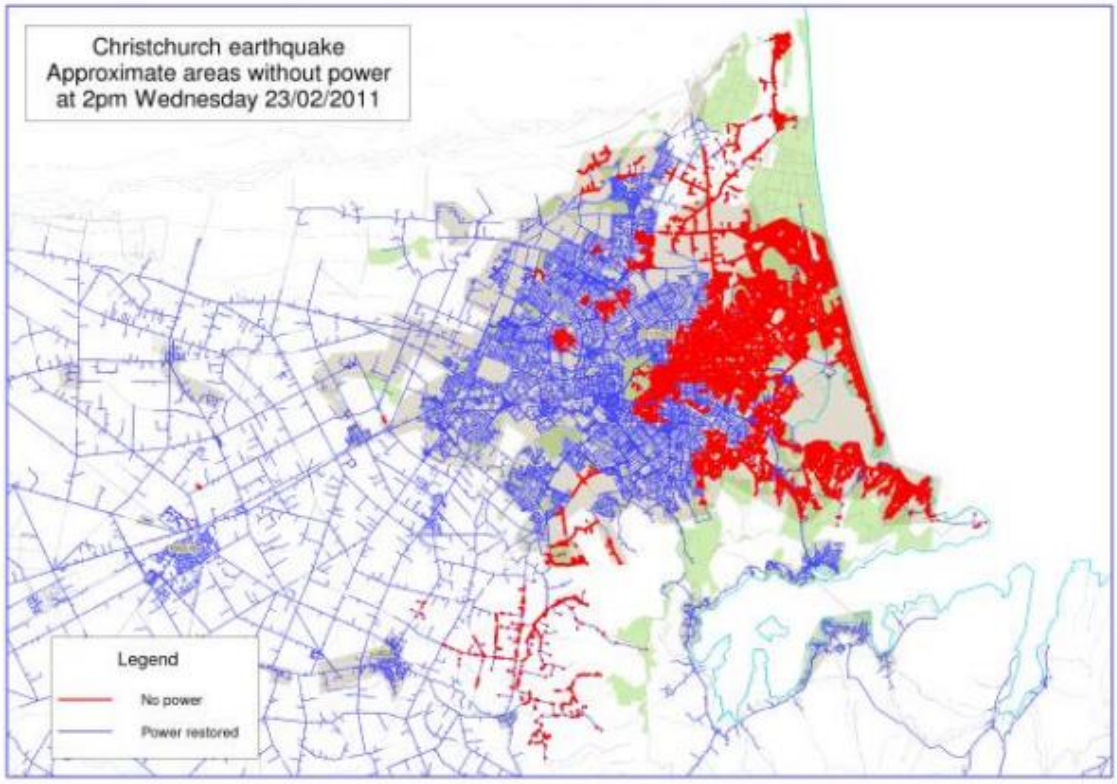


Figure 2: Electrical Outage Map one day after 22nd February Earthquake (courtesy Orion N.Z. Ltd).

Figure 4: Sumner substation boulder damage.

Figure 6: Earthquake damaged 11 kV steel and lead armoured cable, and above embedded in fractured concrete, a damaged 66 kV oil-filled cable.

Note how infrastructure, such as power cables, water and sewerage pipes was damaged.

Figure 16: Digging up multiple faulty 11 kV cables.

2014 PENROSE CABLE TRENCH FIRE

On Sunday 4/5 October 2014 there was a major power outage that affected 39,000 customers, and power was switched off to 75,339 customers to allow repairs in the substation.

What happened

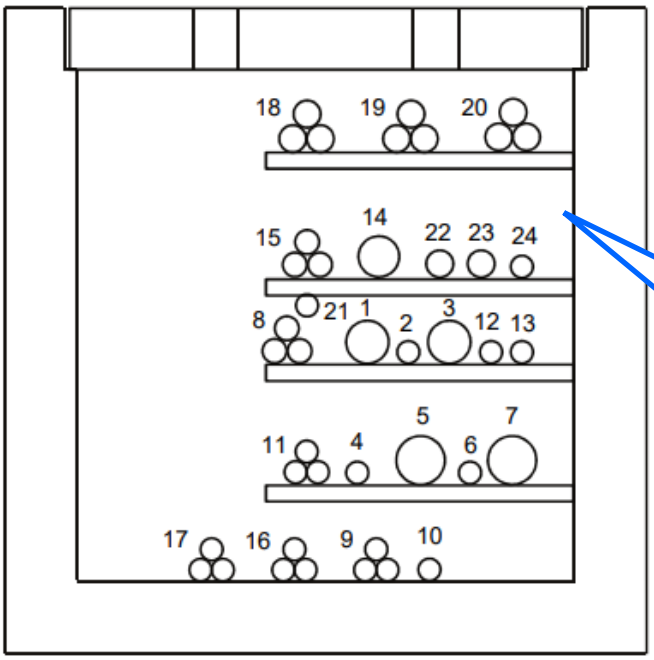
There was an early morning fire at Transpower's Penrose Substation due to an electrical failure of a cable joint in an MV power cable owned by Vector.

When a cable (1966 vintage) leaked, and a new piece was spliced in. But the new piece was too long and was bow shaped, leading to joint failure. This became an ignition source.

Learnings

Neither Transpower nor Vector had apparently identified a trench fire as a risk. Thirty-eight cables, including control cables, were damaged.

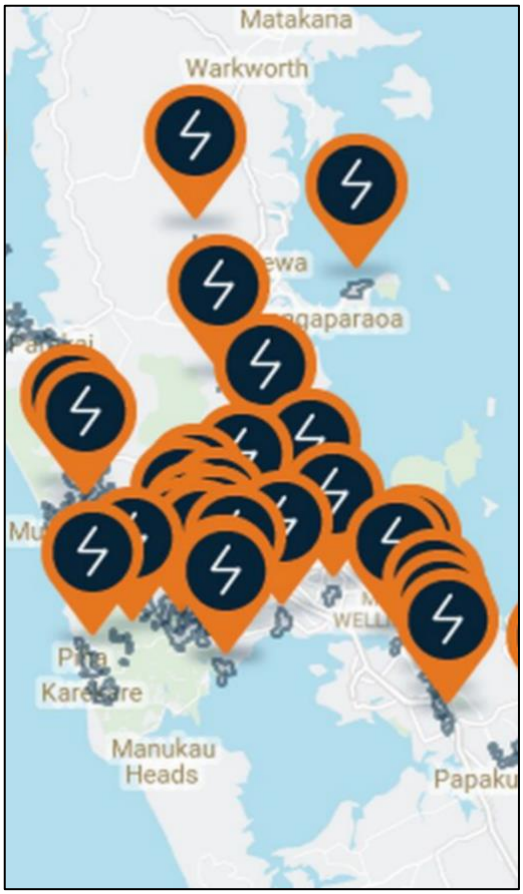
At the time of the fire, there were twelve 33 kV circuits, two 22 kV circuits and six 11 kV circuits installed in the cable trench (as shown in the following diagram). These cables supplied substations to the east of the Penrose site, primarily from the 33 kV busbars. There were also four 33 kV cables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



Note the layout of the cable trench. It was quite full, even using cable racks above ground.

2018 POWER OUTAGES CAUSED BY GALES

On 10 April 2018 in Auckland, and north of Auckland, gales caused trees to fall over and caused other damage.



What happened

The storm damage caused over 150 power outages and 180,000 homes and businesses were affected.

Learnings

After the storm, there was limited ability from the distribution company to deal with this number of outages at once.

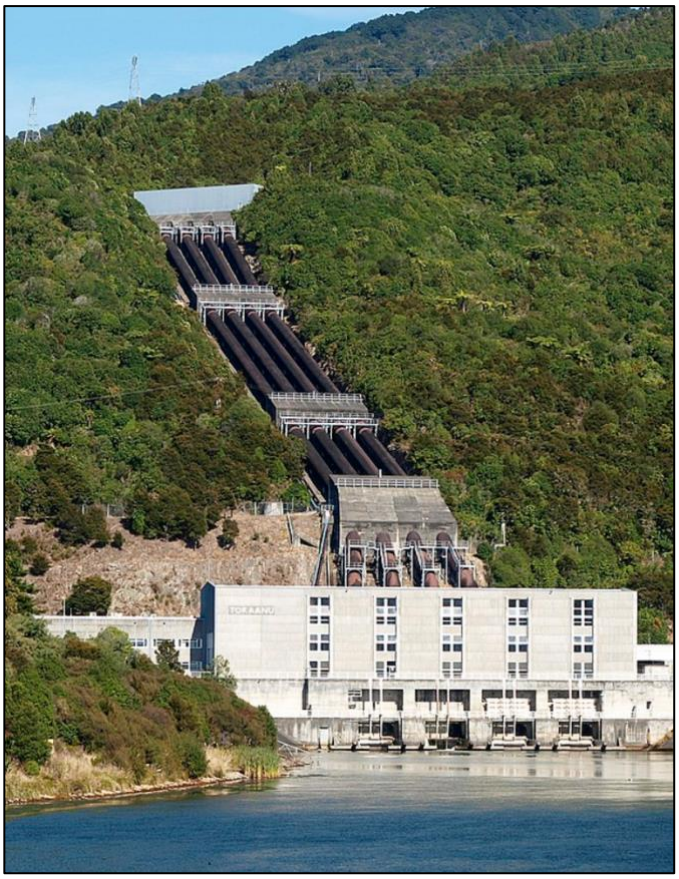
Fifteen hundred customers were affected for a week.

Tree lopping and falling-tree risk management must be an ongoing high priority endeavour.

This is an example of a weather related incident where existing swampy wet soil followed by strong winds pushed the power lines over in Horowhenua.

2021 SUPPLY/DEMAND MISMATCH

On 9 August 2021 New Zealand's generating capacity was unable to meet demand. About 20,000 homes in the central and eastern North Island lost power.



What happened

There was a cold snap caused by a passing polar storm that sent temperatures plunging across the country and pushed up demand for heating.

The network lost generation suppliers due to a range of factors.

1. The storm stirred up weeds preventing electricity generation at Genesis Energy's 240 Megawatt Tokaanu hydro power station on the Tongariro River.
2. Wind speeds also dropped during the evening, reducing the contribution of wind generation.
3. There was no back up generation available. Transpower (operator of the national power grid), miscalculated how much power was going to be needed, and didn't request the Huntly power station to have the additional generating capacity available. Note: Huntly is a large capacity generator but needs a long lead-in time to start up.

Transpower sent out an advisory notice to generators at 6.42am on Monday noting it had concerns about meeting peak evening demand and followed that up shortly after 1pm with a warning advising them to put more generation into the market. At 5.10pm Transpower advised of a grid emergency.

Genesis said that by then it was too late for the company to fire-up their third Rankine coal-fired turbine at its Huntly power station in time for it to help meet the peak evening demand.

On top of that, Transpower admitted it had asked some power companies to cut twice as much demand as was needed, due to an error. For example, Tiwai Point Smelter was mistakenly told to cut consumption by a massive 993 Megawatts.

Learnings

There is a need for some changes to how the power system and electricity market operate to ensure security of supply.

For example, should more quick-start generators be available on stand-by, or other storage options be explored? (At the moment, there is no financial incentive to generators to maintain such generatrion capacity on standby.)

Contact Energy's Otahuhu B combined cycle gas turbine ceased generation in 2015. Mighty River Power's Southdown gas fired power station also ceased operation at the end of 2015.)

3: LESSONS TO BE LEARNT

There are a range of lessons from the power failures covered in this session, and these can be applied to other infrastructure also.

AUCKLAND POWER SUPPLY FAILURE

Auckland's 1998 power failures provided some key lessons.

1. Entities need to have comprehensive asset management plans, and monitoring and risk assessment is fundamental to network reliability.
2. Engineers need to understand the risks in infrastructure and insist on being heard.
3. When there is a large-scale crisis, bring in fresh eyes to develop solution options. Those closest to the crisis often can't see the potential solutions.
4. Hand pick the best organisations and best people to create and execute the recovery plan. Use 'cost plus' contracts to focus on solving the problem. (The damage done to the Auckland businesses as a result of the long outage was horrendous.)
5. Get started with what can be done. Don't wait for a complete solution and innovate 'on the fly'.

GENERAL LESSONS

Other learnings from power failures are:

- Ensure that there is redundancy in the infrastructure.
- Have a system in place to manage the situation when things do go wrong.
- Respond early and accurately to warning signs.
- Get outside help (people with other perspectives and vantage points.)
- Formalise requirements and performance levels contractually and audit compliance when outsourcing business critical technology systems.
- Learn from mistakes and apply those lessons in your future endeavours. (Involvement in a failure doesn't end your career.)
- Valuable lessons can get lost in history. E.g. Many people in the audience probably didn't know about the 1998 power crisis in Auckland and what lessons we can learn from it.

EXAMPLE: SINGLE FUEL PIPELINE

These lessons apply to other types of infrastructure too.

For example, the 168-kilometre-long fuel pipeline from Marsden Point refinery to Wiri, Auckland, was damaged between 26-28 Aug 2014 and it ruptured on 14 Sept 2017. It carried Jet-A1 (aviation fuel), petrol and diesel.

What happened

The pipeline was damaged by a digger (who didn't report it at the time) and about three years later the pipeline failed under pressure. Once the rupture in the pipeline was found, it needed repair.

The pipeline outage lasted 10 days.

There were no Jet-A1 road tanker load-out gantries at Marsden Point Refinery (only for petrol and diesel fuel).

As a consequence, flights were disrupted and there was a general petrol and diesel fuel shortage in Auckland.

Learnings

With a sinlgle pipeline, there was no redundancy. Not even an option for transporting Jet-A1 fuel by road.

There was no accountability from the Kauri miner who was close to the work. If the worker who had scraped and weakend the pipe had reported it instantly, the consequences would have been more manageable.

It also highlighted the importance of Marsden Point as a fuel refinery and bulk-fuel delivery point.

And now that Marsden Point is permanently closed, we are totally reliant on offshore oil. There is no redundancy if that offshore tanker delivery system is disrupted. This is a significant risk to the country.

The site of the pipe rupture.

The scrape marks where the pipe was damaged by the digger.


Marsden Point to Wiri pump station outside Kumeu. (One of two tandem pump stations.)

4: Q&A

How do you influence clients who are driven by cost?

As there are not enough incentives to create redundancy, the role of engineers is critical in ensuring that maintenance and monitoring occurs. The Three Waters highlights the state of water supplies around the country which haven't had ongoing investment and maintenance. Engineers need to step up and raise issues.

What helped Mercury Energy be responsive in the 1998 CBD power failure in Auckland?

Mercury Energy were in a horrendous position – they had lost cables to the CBD. But they were focussed on repair. It was not until 'fresh eyes' were applied to the problem, that Plan B could be created.

In the 1998 CBD power failure in Auckland, could the outage have been prevented by load-shedding off the cables?

Operationally, it may have been a better strategy to load-shed, as each time a cable failed, the remaining cables took on even more load.

Will the Three Waters reforms increase infrastructure responsibilities by councils?

We need to improve our thinking about having redundancy in our infrastructure, so we know that if one thing fails, we have redundancy. Having the right people, such as engineers, at higher levels (such as on Boards) mean we are heard and can influence and add a voice to decision making. (A single water pipeline from a centralised water treatment facility to rural towns was used as an example of single point of failure.)

5: REFERENCES

Andrew Massie & Neville R. Watson, IMPACT OF THE CHRISTCHURCH EARTHQUAKES ON THE ELECTRICAL POWER SYSTEM INFRASTRUCTURE, 5, Researchgate.

https://www.beehive.govt.nz/release/auckland-cbd-power-failure-inquiry

https://teara.govt.nz/en/photograph/33418/auckland-power-supply-failure-inquiry

https://wikimili.com/en/1998_Auckland_power_crisis

https://www.tonkintaylor.co.nz/news/2019/6/inside-the-vector-tunnel/

https://transpower.maps.arcgis.com/

Hobson Street Upgrade: https://www.youtube.com/watch?v=YpdNkmlgBxc

https://www.civildefence.govt.nz/assets/Uploads/lifelines-forum/lifelines-forum-2010-urgwin.pdf

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