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Creating a safer state with electricity and gas

Garvoc Fire (The Sisters) 17 March 2018

Technical investigation report

VICTORIA State Government

Preface

This technical investigation report has been prepared by Energy Safe Victoria (ESV) pursuant to the objectives, powers and functions conferred on it by The Electricity Safety Act 1998 (Act).

Specifically, these include, amongst other things, to investigate events or incidents, which have implications for electricity safety and to regulate, monitor and enforce the prevention and mitigation of bushfires that arise out of incidents involving electric lines or electrical installations and to monitor and enforce compliance with this Act and the regulations.

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Summary

On 17 March 2018, at approximately 20:49 Australian Eastern Standard Time[1] (AEST), a high wind event passing through Victoria's South West Region caused a fault on the electrical network and a fire in the Terang area, known as the Garvoc Fire that resulted in significant property damage.

The fire originated at or close to the location of Pole 4 of the Sparrow Spur line, The Sisters, on the Powercor Australia Limited distribution network. The pole is also identifiable by its unique line information system number (LIS) 20675.

Energy Safe Victoria's (ESV) technical investigation has established the following:

- On 17 March 2018, the closest weather stations to the ignition site recorded north-westerly wind gusts of up to 104 kilometres per hour at or around 20:00 AEST
- Pole 4 structurally failed at the top of the pole stakes causing the upper section of the pole to fall to the ground
- Powercor Australia Limited's high voltage protection equipment operation records show that a phase-to-earth event occurred at approximately 20:49 AEST downstream of the Automatic Circuit Recloser (ACR) located at Pole 2 on The Sparrow Spur line, The Sisters, which is upstream of the failed pole on the same line. The ACR did not reclose, which de-energised the line as expected.

ESV has investigated this incident and has concluded the following:

- The most likely source of ignition for the Garvoc Fire was the failure of Pole 4 and the subsequent contact of the high voltage conductor with the ground and vegetation at or around 20:49 AEST
- The engineering analysis of the remaining pole sections concluded that the structural failure of Pole 4 was caused by long-term material degradation due to decay and termite infestation. This resulted in the timber's reduced compressive and flexural/bending strength, development of a sizeable internal cavity in the region of the point of failure, and a reduced overall capacity that saw the pole's actual remaining strength exceeded under the prevailing wind conditions
- A competent inspection and sound test of the pole in November 2017 would have identified the material degradation present when the pole failed
- Powercor Australia Limited failed to identify that Pole 4 had a sizeable internal cavity which compromised the pole even though specific tests (sound test) exist to identify internal cavities
- The failure of Pole 4 is considered to be an unusual event in Victoria, however the failure of poles at the top of the reinforcing stakes is a phenomenon recognised Australia-wide as having occurred in other jurisdictions.

ESV will now undertake a formal legal review to determine the nature and extent of any breaches to the Act or Regulations and the extent of any enforcement action to be taken.

Based on the results of the Pole 4 technical assessment, and the review of Powercor Australia Limited's asset inspection records and processes, ESV will also:

- audit other poles in the Terang region, particularly poles similar to Pole 4
- audit a wider sample of reinforced poles across the Powercor Australia Limited network.

[1] All time references in this report refer to Australian Eastern Standard Time.

Report structure

In this report, the:

- introduction provides information about: the investigation's scope, objectives, and methodology, and the prevailing declarations at the time of the incident, and the investigation's sequence of events
- background information section provides information about the prevailing weather, Pole 4's condition, construction history, relevant standards and the prevailing asset management and inspection regime
- asset management practices section provides a review of the asset inspection regime and whether it should have identified any concerns with the condition of Pole 4
- technical investigation section provides information about the testing conducted on the remaining parts of Pole 4 and its key findings
- findings and conclusions section summarises the investigation's key findings, which involve the source of the fire, the engineering assessment, the network asset inspection process, and ESV's next steps.

Introduction

Scope

This report details the findings of an Energy Safe Victoria (ESV) technical investigation into the causes of, and contributing factors to, the Sparrow Spur pole failure and fire that originated at or near Pole 4 on the Sparrow Spur line, The Sisters, on the Powercor Australia Limited distribution network on 17 March 2018. The pole is also identifiable by its unique line information system number (LIS) 20675,

The investigation only details the evidence gathered to support the technical conclusions reached as well as outlining the relevant standards, plans or procedures that apply to the distribution network at this location and the implications for asset management.

Objectives

ESV's investigative objectives were to:

- identify the entities involved
- establish the initial facts and possible causes of the incident
- identify any relevant standards and work practices that may have been a factor.

To meet these objectives, ESV sourced specific information that included:

- Bureau of Meteorology (BOM) data from weather stations[2] closest to the ignition source
- engineering analysis and testing of the failed pole
- Powercor Australia Limited's:
  - incident report (submitted into the OSIRIS reporting system)
  - protection equipment operation records
  - electrical system diagram for the Terang (TRG) 002 feeder
  - detailed route plan and design information for the area that includes Pole 4 as recorded when initially constructed (and subsequent versions)
  - asset inspection requirements for reinforced poles
  - electrical event timeline in relation to the TRG 002 feeder on the day of the incident, including reports of any initiating events
  - Bushfire Mitigation Plan
  - Zone Sub Station (ZSS) protection settings for the TRG 002 feeder on 17 and 18 March 2018 including any protection settings from any related field re-closer devices
  - Total Fire Ban protection operations for the TRG 002 feeder from the TRG ZSS for 17 and 18 March 2018
  - asset inspection records, maintenance history, staking/steel reinforcement date and conductor size/type information for Pole 4.
- the construction standard applicable when the 22 kilovolt (kV) high voltage (HV) feeder, which includes Pole 4, was constructed.

ESV also used Section 134 of the Electrical Safety Act 1998 (Power of enforcement officer to require information or documents for the purpose of investigating a serious electrical incident) to require the provision of certain information.

[2] Warrnambool and Mortlake.

Methodology

ESV's investigative methodology was to:

- require and analyse specific information from Powercor Australia Limited
- review and analyse TRG 002 feeder protection equipment operation records
- review weather records from the closest BOM weather stations
- inspect and test the remaining parts of Pole 4 analyse photos taken at the site on the day following the incident
- review reports as provided by Powercor Australia Limited and the Country Fire Authority (CFA).

Investigation sequence of events

On 17 March 2018, the high wind event occurred.

On 18 March 2018:

- Victoria Police requested ESV attend the incident site to help identify the cause of ignition near the TRG ZSS
- ESV dispatched an enforcement officer at 15:20 AEST to the incident site to meet with the Powercor Australia Limited Network Availability Officer and representatives from Victoria Police.

On 19 March 2018, ESV's Head of Regulatory Assurance produced the South West Fires Summary Update for ESV Senior Management[3].

On 26 March 2018, ESV quarantined the remaining parts of the failed Pole 4, stakes, and associated pole hardware under Section 141of the Electricity Safety Act 1998.

On 3 April 2018, ESV required Powercor Australia Limited to supply relevant documents and information under Section 134 of the Electrical Safety Act 1998.

On 10 April 2018:

- Powercor Australia Limited provided relevant documents and other information requested by ESV
- ESV engaged a forensic engineering consultant (FMG Engineering) to develop a scope for the testing and assessment of Pole 4's remaining parts and produce a report based on the results.

On 13 April 2018, ESV revisited the incident site to collect more information relating to the electrical assets.

On 15 May 2018, the remaining parts of Pole 4 were transferred from the quarantine area of Powercor Australia Limited's Ballarat office to the Creswick Timber Training Centre for visual assessment and species identification, and to be milled by a timber machinist in preparation for destructive testing.

From 18 May to 31 May, the remaining parts of Pole 4 were analysed and subjected to a series of tests, the results of which were communicated to FMG Engineering.

On 2 July 2018, ESV received FMG Engineering's final Pole 4 condition report.

[3] Fox, B, Head of Regulatory Assurance, South West Fires Summary Update, March 2018, Energy Safe Victoria, State Government of Victoria, Melbourne.

Background information

Incident background

On 17 March 2018, at approximately 20:49 Australian Eastern Standard Time (AEST), a high wind event passing though Victoria's South West Region caused faults on the electrical network and a series of fires in the Terang area that resulted in the destruction of eighteen homes and forty-five sheds. There were no fatalities or serious injuries.

One of the fires originated at or close to the location of Pole 4 in a paddock at 974 Sisters-Garvoc Road, The Sisters.

The power line at Pole 4 is constructed with a three phase steel conductor supplied from the TRG 002 22kV HV feeder and is supplied through the automatic circuit recloser (ACR) TRG2-22617 located at Pole 2 on The Sparrow Spur line, The Sisters. Electricity network drawings[4] identify the location of the failed pole as Pole 4 on The Sparrow Spur line. Figure 1 shows Pole 4 prior to its failure and the reinforcing attached to the base of the pole.

Operations records

Table 1 shows an excerpt from the Powercor Australia Limited TRG 002 feeder protection equipment operation information. The excerpt indicates:

- there was a single Red Phase phase-to-ground (P-G) event that resulted in The Sisters Pole 2 ACR tripping at approximately 20:49 AEST
- the ACR did not reclose, which de-energised the line.

Table 1: Terang 002 (The Sisters Pole 2 ACR) feeder protection equipment operation information

Number	Time (AEST)(+11)	Type	Magnitude @ Trip	Reclose
1	20:49:47.006	Red to ground (P-G)	17A	No (single shot trip)

The TRG 002 protection equipment operation event record is consistent with a high voltage conductor-to-ground contact at Pole 4 of The Sparrow Spur.

[4] Powercor Australia Limited, Detailed Route Plan VJ8_1855_G (DOC_18_6554).pdf &Op Diagram TRG-CENT (DOC_18_6553).pdf, 2018.

Figure 1: Pole 4 prior to failure (taken 5 December 2012)

Declarations

The declarations relating to the period of the incident involved a Total Fire Ban (TFB) day, a Hazardous Bushfire Risk Area (HBRA), and Powercor Australia Limited special protection settings for TFB days.

Total Fire Ban day

On 17 and 18 March 2018, TFB days were in place for the South-west Fire District, which includes the Terang area[5].

Hazardous Bushfire Risk Area

Figure 2 shows a Graphical Information System (GIS) area map of the incident site in relation to the CFA declared Low Bushfire Risk Area (in green) and the HBRA area (in amber).

[5] Country Fire Authority 2018, State Government of Victoria, Melbourne, viewed 7 May 2018, www.cfa.vic.gov.au/warnings-restrictions/history-of-tfbs.

Figure 2: GIS incident site area map

Powercor Australia Limited special protection settings

Powercor Australia Limited has an ESV accepted Bushfire Mitigation Plan (which includes any actions required) for managing risk on TFB days. The plan, which considers a number of factors (including environmental), involves initiating[6] enhanced protection setting functionality for specific (listed) assets. The TRG 002 Sisters Pole 2 ACR, which was connected upstream of the same 22kV feeder (TRG 002) as pole 4, is listed as an identified asset.

On the day of the incident (17 March 2018):

- a Red phase-to-earth event occurred downstream of the TRG 002 Sisters Pole 2 ACR located at Pole 2, which is on the same line as the failed pole[7,8]
- the protection settings were applied on 17 March 2018 and then removed on 18 March 2018.

As expected, the ACR operated once and remained open isolating the line until inspected.

Prevailing weather information

Warrnambool and Mortlake are the closest weather stations to the incident site. Prevailing weather information on the day has been sourced from the Bureau of Meteorology (BOM) website[9].

Figure 3 shows an excerpt from the Warrnambool Weather Station records, which indicate that on 17 March 2018 at 20:00 AEST, north westerly winds with a maximum gust of 104 kilometres per hour were recorded[10].

[6] This involves supressing (deactivating) an ACR's auto-reclose function. This means the protection does not reclose/re-energise the line after an operation (as normal on a normal/undeclared day).

[7] Powercor Australia Limited, Total Fire Ban Action Plan, Attachment A, 2018.

[8] Powercor Australia Limited, protection equipment operation information for the Terang (TRG) 002 feeder, 17 March 2018.

[9] Bureau of Meteorology 2018, Australian Government, viewed 14 April 2018, www.bom.gov.au.

[10] While wind speeds of 104 kilometres per hour are considered to be high, they are not excessive, with utility poles in the immediate area expected to have sufficient strength to withstand wind speeds of at least 180 kilometres per hour.

Figure 3: excerpt from the Warrnambool weather record for March 2018

Warrnambool, Victoria
March 2018 Daily Weather Observations

Date	Day	Temps Min °C	Temps Max °C	Rain mm	Evap mm	Sun hours	Max wind gust Dirn	Max wind gust Spd km/h	Max wind gust Time local
16	Fr	5.9	23.7	0			NE	31	10:40
17	Sa	12.0	34.1	0.6			NW	104	20:00
18	Su	12.9	20.2	2.8			W	96	11:15
19	Mo	10.7	23.2	1.4			NW	65	13:08

Figure 4 shows an excerpt from the Mortlake Weather Station records, which indicate that on the 17 March 2018 at 20:08 AEST, north westerly winds with a maximum gust of 104 kilometres per hour were also recorded.

Figure 4: excerpt from the Mortlake weather record for March 2018

Mortlake, Victoria
March 2018 Daily Weather Observations

Date	Day	Temps Min °C	Temps Max °C	Rain mm	Evap mm	Sun hours	Max wind gust Dirn	Max wind gust Spd km/h	Max wind gust Time local
16	Fr	5.5	26.4	0			WNW	35	13:26
17	Sa	10.7	34.0	0			NW	104	20:08
18	Su	12.5	21.1	0.4			WNW	76	11:28
19	Mo	9.1	23.5	0.2			W	57	12:36

See Appendix A for more information.

Emergency Management Victoria information

Emergency Management Victoria provided ESV with a more detailed weather record from the Mortlake Automatic Weather Station to establish whether the 17 March 2018 high wind event was unusual[11]. The record covered the period from 09:00 AEST on 17 March 2018 to 08:30 AEST on 18 March 2018, and while it provided more information about the intensity of the wind and when wind conditions changed, it offered no evidence that the wind event was exceptional.

Pole 4 condition, construction history, and ongoing maintenance

Pole 4 was:

- a Mountain Grey Gum[12] pole installed in 1964 and originally constructed to specifications stipulated by State Electricity Commission of Victoria (SECV) drawing VX9/8A
- 10.5 metres long (in ground to a depth of 1.5 metres; above ground to a height of 9 metres)
- double staked using the RFD 600X2 reinforcing system (commonly known as RFD staking) in 1994
- separated from its two nearest adjacent poles by a distance of 283 metres and 367 metres
- converted from Single Wire Earth Return (SWER - single wire construction) to three phase (three wire construction) in 2001 to Powercor Australia Limited construction standard EJ101[13]
- supporting three galvanised steel conductors each made up of three strands of 2.75 millimetre diameter galvanised steel
- leaning 1.2 metres perpendicular to the line route (a column eccentricity of 1.2 metres with respect to the point of failure) on 5 December 2012 as per Figure 1
- subjected to regular asset inspections, with Powercor Australia Limited providing inspection records spanning the period 2005 to 2018[14].

[11] State Control Centre (Intelligence Section), mortlake aws_terang fire.xlsx, viewed May 2018.

[12] Illic, Jugo. (2018). Wood Identification Results. Melbourne: Know Your Wood. Melbourne.

[13] Powercor Australia Limited. EJ 101 - Distribution Construction Standard Three-Phase, Intermediate Structure - Wood Pole. Version 2. 7 December 2012, Melbourne.

[14] Energy Safe Victoria, Pole 4 Asset Inspection Records (Compilation), 2018, Energy Safe Victoria, Melbourne.

Figure 5 shows a section of the TRG Central 22kV electrical network diagram and the:

- TRG 002 feeder (in red)
- location of the ACR that operated TRG2-22617 (The Sisters P2 ACR)
- Pole 4 (P4) fault location.

Figure 5: the TRG Central 22kV electrical network diagram and incident location

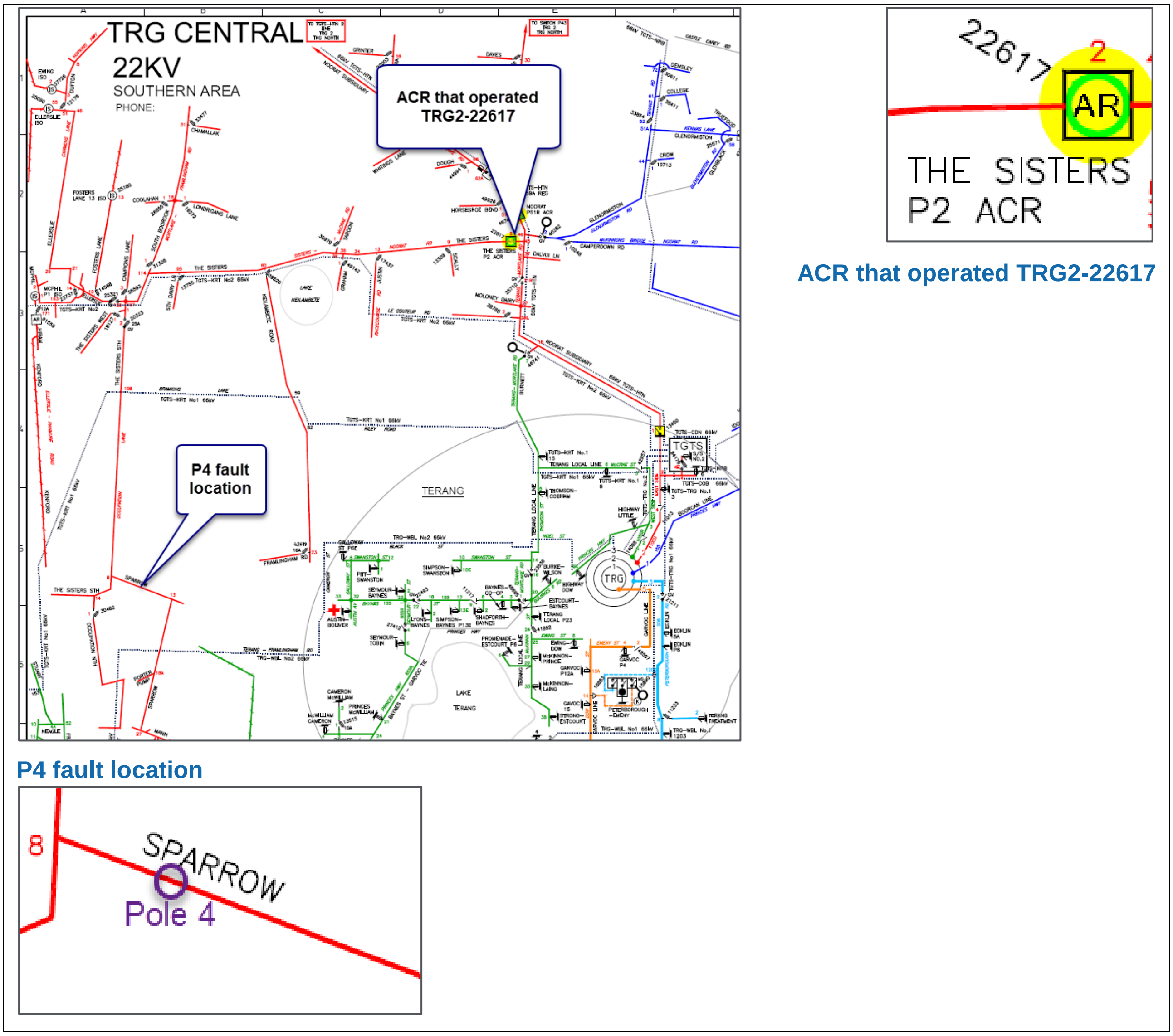
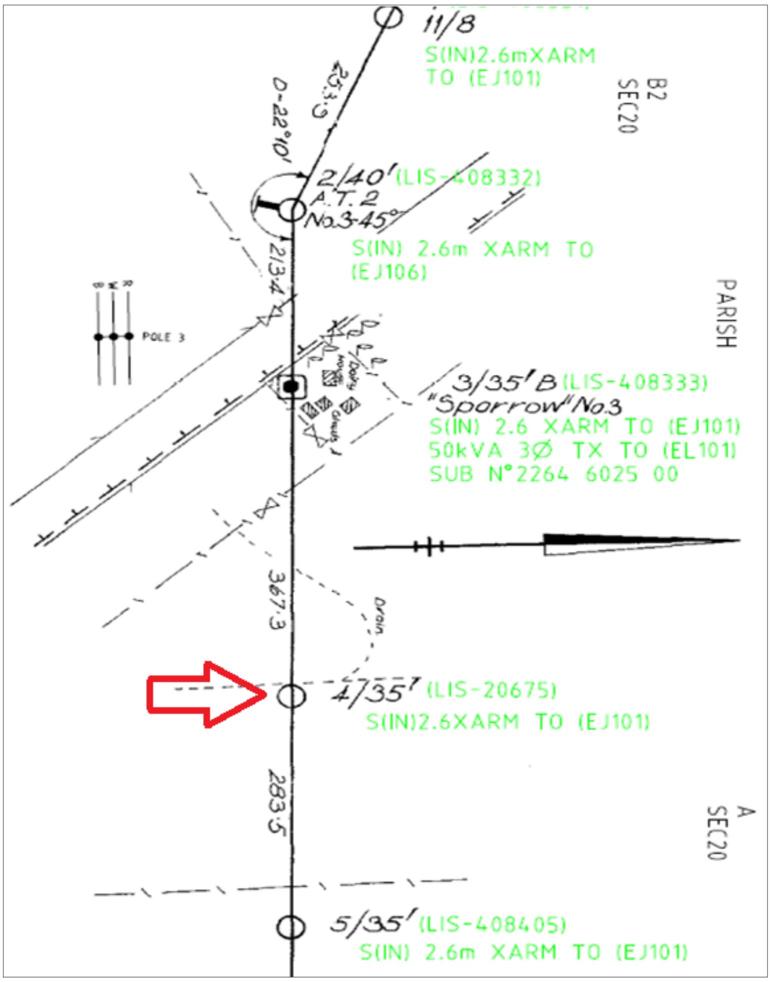


Figure 6 shows a section of the detailed route plan identifying the location of Pole 4 (in red) and a reference to its construction standard.

Figure 6: Pole 4 site plan and construction standard detail



Construction history

Records indicate that the pole was originally installed in 1964. Given its age and the lack of historical records, it cannot be established whether the original construction and installation complied with the relevant design and construction standards in place at the time[15].

Powercor Australia Limited provided ESV with detailed route plans of the area around Pole 4 dating back to 1975 that:

- record details about the design and act as the area's as-built record
- explain the structure types and refer to relevant construction standards
- are updated when new construction work requires an asset design change.

The most recent detailed route plan indicates design and construction changes up until May 2010. Historical details relating to the line include the following:

- New poles were added to, or relocated from the line in 1976, 1984, and 1986
- A new spur was added in 1980
- The line (including Pole 4) was rebuilt (converted from Single Wire Earth Return (SWER) to three phase (three wire construction) to the Powercor Standard EJ101 in 2001.

[15] Distribution Engineering Department, State Electricity Commission of Victoria, Single Wire Earth Return, Pole Construction (revised in 20 April 1971 and 11 October 1994), 8 October 1957, Melbourne.

Asset management practices

This chapter outlines ESV's investigation of Powercor Australia Limited's asset management practices including:

- The review of relevant asset information, including the construction history of Pole 4, and the relevant standards applying to these network assets and their maintenance
- The review of the records of inspection and repair for the network assets involved. Refer to Appendix B for details of the asset inspection process, and Appendix C for an assessment of the asset inspection process as applicable to this investigation.

Asset management

Powercor Australia Limited operates an asset management regime which includes the contracting out of its network asset inspection services to Electrix Pty Ltd for more than 10 years. Under this agreement, Electrix Pty Ltd inspectors record site inspection information, which is transferred to Powercor Australia Limited's maintenance section.

Documents that have been identified as relevant to the inspection of reinforced poles and this investigation include Powercor Australia Limited's:

- Electricity Safety Management Scheme (ESMS)[16]
- Network Asset Maintenance Policy for Inspection of Poles[17]
- Bushfire Mitigation Plan (BMP)[18]
- Asset Inspection Manual (AIM)[19].

Reinforcing (RFD staking)

Typically, reinforcing (RFD staking) is used when a pole's condition at or around ground level has deteriorated to the point the pole can be classified as unserviceable and the assessment has determined the pole is suitable to be reinforced. Powercor Australia Limited uses a number of different pole reinforcing systems, including various RFD reinforcing systems[20]. RFD 600 is the original staking design used by the SECV.

The failure of Pole 4 is considered to be an unusual event in Victoria, but the type of failure (at the top of the reinforcing) is a recognised phenomenon. Poles Australia-wide are known to fail at the top of their reinforcing due to unusually high wind events or a reduction in the pole's structural integrity.

[16] Powercor Australia Limited, Electricity Safety Management Scheme, latest accepted version by ESV on 13 January 2014.

[17] Powercor Australia Limited, Network Asset Maintenance Policy for Inspection of Poles, Document No: 05-C001.D-390.

[18] Powercor Australia Limited, Bushfire Mitigation Plan, Electricity Safety (Bushfire Mitigation) Regulation 2013, Revision 4.1b, Document No: 05-M810, accepted by ESV on 30 March 2017.

[19] Powercor Australia Limited, Asset Inspection Manual, Document No: 05-M450, Section G.12-WI, Issue 2.6.

[20] For more information about RFD reinforcing (staking) systems see http://www.pmgintl-usa.com/pmg.html.

Relevant standards

The standards relevant to these network assets and the circumstances of the event involve:

- AS/NZS 4676-2000 Structural Design Requirements for Utility Services Poles[21]
- Guidelines for Design and Maintenance of Overhead Distribution and Transmission Lines[22]
- AS/NZS 7000:2016, Overhead Line Design - Detailed Procedures[23]
- Drawing VX9/8A, Single Wire Earth Return, Pole Construction (the standard at the time of construction in1964)[24]
- Powercor Australia Limited's internal standards:
  - EB 141, Distribution Construction Standard, Pole Reinforcement Systems[25]
  - EJ 101, Distribution Construction Standard, Three Phase, Intermediate Structure - Wood Pole[12].

Inspection practices

Network Asset Maintenance Policy for Inspection of Reinforced Poles

The network asset maintenance policy for inspecting reinforced poles provides a high-level description of these asset inspections and their requirements:

- A full inspection of the pole and pole top assets is conducted every five years and requires assessing the condition of the reinforced wood pole and accounting for its classification. It includes excavation, treatment, a pole assessment (including drilling), visual inspection, and a sound test.
- A limited inspection (above ground inspection) is conducted on an alternating five-yearly cycle (occurring two and a half years after the full inspection). It includes a visual inspection of the pole and pole top assets and a sound test, but excludes excavation, treatment, and pole assessment (drilling).

Both inspection types include the inspection of electrical assets between poles (the AIM provides a more detailed description of what the inspections involve).

The policy also stipulates that wood poles reinforced with staking should be inspected:

- externally:
  - from 2 metres above ground to the pole top for deterioration, fungal attack, lightning strikes, significant cracking and or bowing, and termite infestation
  - from ground line to 2 metres above ground for deterioration, termite infestation, and the security of the stakes/steel reinforcement system.
- below ground to a maximum depth of 300 millimetres for termite infestation and corrosion of the stakes/steel reinforcement system
- internally with a 12 millimetre auger bit to ascertain the depth of sound timber…for staked poles at 400 millimetres below the top of the stakes/steel reinforcement system.

A limited inspection exclude tasks specific to below ground and drilling inspections.

[21] Committee CE-19, AS/NZS 4676-2000, Structural Design Requirements for Utility Services Poles (superseding DR 98206), 2000, Standards Australia. (Withdrawn 9 March 2017.)

[22] Electricity Supply Association of Australia, Guidelines for Design and Maintenance of Overhead Distribution and Transmission Lines. The Association, Melbourne.

[23] Committee EL-052, AS/NZS 7000:2016, Overhead Line Design - Detailed Procedures (superseding AS/NZS 7000:2010 and DR AS/NZS 7000:2015), 2016, Standards Australia.

[24] Distribution Engineering Department, State Electricity Commission of Victoria, Single Wire Earth Return, Pole Construction (revised in 20 April 1971 and 11 October 1994), 8 October 1957, Melbourne.

[25] Powercor Australia Limited. EB 141 - Distribution Construction Standard Pole Reinforcing Systems. Version 3. 8 December 2017, Melbourne.

Bushfire Mitigation Plan and Asset Inspection Manual

Several inspection types are specified by the BMP and the AIM, with the BMP requiring a full inspection and a limited inspection to be conducted on alternating five-yearly cycles (occurring two and a half years apart)

The AIM includes a further requirement that every inspection of a pole with a reinforcing systems have a sound and a visual test conducted above ground.

The last inspection prior to failure (in November 2017) was a pole top inspection, which did not identify the cavity, while the asset inspection records for the last 13 years, which included three full inspections (the last occurring in May 2015), do not show that a sounding test identified an issue with the pole.[26]. Records provided by Powercor show that the pole had 100 mm of sound wood in 2010 and 50 mm in 2015. Powercor Australia Limited considers a pole to be unserviceable if it has less than 30 millimetres of sound wood irrespective of species.

ESV cannot establish whether the sound inspection of Pole 4 was carried out at the last inspection, however it is ESV's and expert[27] opinion that a competent sound test of the pole in November 2017 is likely to have identified the cavity.

ESV conducted a series of bushfire mitigation audits during 2017/18, one of which (in February 2018) focussed on pole inspection practices and found no systemic issues[28].

See Appendix B for more information about Powercor Australia Limited's network asset inspections, policies and requirements.

See Appendix C for more information about Powercor Australia Limited's network asset inspection records.

Next steps

As a result of the Garvoc Fire (The Sisters) investigation, ESV will now initiate a more formal investigation of Powercor Australia Limited's current asset inspection practices as well as confirming the current condition of:

- other poles in the Terang area by auditing poles on the same feeder or in the same area as Pole 4
- reinforced poles generally by auditing the Powercor Australia Limited network.

[26] Energy Safe Victoria, Pole 4 Asset Inspection Records (Compilation), 2018, Energy Safe Victoria, Melbourne.

[27] Dr. Ewart, D. (2018). Inspection of Pole LIS # 26435, The Sisters. Melbourne.

[28] ESV audit report titled "CitiPower Powercor 2017/18 Bushfire Mitigation System Audit Final Report" on the ESV website at https://www.esv.vic.gov.au/about-esv/reports-and-publications/technical-reports-and-publications/electrical-safety-audit-reports/

Technical investigation

This chapter outlines the results from:

- the forensic testing and assessment of Pole 4 via the destructive testing of samples and the visual inspection of Pole 4's remaining pieces
- the inspection of other asset evidence, including engineering and photographic evidence.

Forensic testing and assessment

ESV engaged FMG Consulting to develop an investigation plan to determine the condition of the pole at the time of failure. On 15 May 2018, the remaining parts of Pole 4 were transferred to the Creswick Timber Training Centre for the following tests:

Test 1: a visual inspection and assessment of the pole in accordance with AS/NZS 4676-2000, Structural Design Requirements for Utility Services Poles[29].
Test 2: species identification[30].
Test 3: strength group testing of a timber section in accordance with AS/NZS 2878-2000, Timber - Classification into Strength Groups[31].
Test 4: visual stress-grading of a timber section in accordance with[29]:

- AS 3818.1-2009, Timber – Heavy Structural Products – Visually Graded
- AS 2082-2007, Timber – Hardwood – Visually Stress-Graded for Structural Purposes.

Test 5: a condition assessment of a timber section in accordance with AS 4349.3-2010, Timber Pest Inspections[32].
Test 6: NATA accredited laboratory testing for[33]:

- moisture content in accordance with AS/NZS 1080.1-2012, Timber - Methods of Test Moisture Content 4676-2000
- density in accordance with AS/NZS 1080.3-2000, Timber - Methods of Test Density
- bending strength and apparent modulus of elasticity, and shear strength (perpendicular to grain) in accordance with AS/NZS 4063.1-2010, Characterization of Structural Timber Test Methods
- compression strength in accordance with AS/NZS 4063.1-2010, Characterization of Structural Timber Test Methods.

Key results

A comprehensive engineering analysis conducted by FMG Engineering (and based on the results from the test series) of Pole 4[29] found evidence of extensive decay and hollowing within the structural failure zone and beyond, which affected the interior regions of the pole.

[29] Eracleous, E. (2018). Engineering Investigation Report. The Sparrow Spur – Pole 4 (LIS #20675). FMG Reference S40461 – 261138, FMG Engineering, Melbourne

[30] Illic, Jugo. (2018). Wood Identification Results. Melbourne: Know Your Wood. Melbourne.

[31] Rule, Rob (2018), Inspection of Failed Power Pole 4 Sparrow Spur Inspection of Failed Power Pole 4 Sparrow Spur, Timber Training Creswick Limited. Creswick.

[32] Dr. Ewart, D. (2018). Inspection of Pole LIS # 26435, The Sisters. Melbourne.

[33] Breitinger, H. (2018). Small Clear Tests on Eucalyptus Cypellocarpa (Mountain Grey Gum) Power Pole, Breitinger Consulting, Maryborough.

The pole's outside diameter at the structural failure zone was 250 millimetres with a 200 millimetre central cavity. The outer material thickness of the failure zone averaged 25 millimetres (ranging between 10 millimetres to 40 millimetres). Sections of the outer material thickness at the failure zone also appeared to be affected by timber decay.

The combined axial-bending design actions at the failure zone (at 1.5 metres above ground) exceeded the pole's combined axial-bending design strength by:

- 7% for the actual wind conditions of 29 metres per second on the day
- 62% for the ultimate design wind speed of 50 metres per second in accordance with Australian standard AS/NZS 4676:2000 "Structural design requirements for utility poles" which requires utility poles to be able to withstand winds of up to 180 kilometres per hour (50 metres per second).

The outer material thickness of Pole 4 needed to be:

- 32.5 millimetres to withstand the actual wind conditions of 29 metres per second
- 60 millimetres to withstand the ultimate design wind speed of 50 metres per second.

A summary of the key observations is as follows:

- Pole 4 shows clear signs of decay and was significantly hollowed, with the hollowing extending well above the top of the stakes/steel reinforcement (possibly by more than 2 metres)
- In terms of strength, the pole's:
  - Design Bending Strength is approximately 36% lower than expected
  - Design Compressive Strength is approximately 73% lower than expected.
- Pole 4 was infested with termites above its base (with active termites found to be infecting the remaining upper section of the pole), below which the remaining pole butt was found to be damp
- Visual inspection and tapping (sounding) showed the extent of the pole's hollowing, which would have been detectable well above the plane of failure, and indicated the loss of integrity above the stakes/steel reinforcement
- The pole was significantly degraded and likely had been that way for many years. A competent inspection of the pole in 2017 would likely have found the same evidence of degradation that was present when it failed in March 2018 (and was observed during testing in May 2018)

FMG Engineering concluded that the structural failure of Pole 4 was caused by long-term material degradation (rot/decay), which resulted in the:

- timber's reduced material strength
- development of a sizeable internal cavity in the region of the failure
- reduced overall capacity that saw the pole's actual strength exceeded and caused it to fail.

See Appendix D for more information about the testing and assessment results.

Photographic analysis

Figure 7 shows an image of Pole 4, which was found to have structurally failed at the top of the pole stakes/steel reinforcement. The photograph shows the:

- remaining pole butt and the upper section, which snapped at the top of the steel RFD 600X2 reinforcing stakes; the stakes/steel reinforcement did not fail
- conductor closest to the ground is in contact with the pole and the ground
- extent of burned grass and vegetation around the failed pole
- armour rods and vibration dampers installed on all three conductor phases.

Figure 7: failed Pole 4, 974 Sisters-Garvoc Road

Findings and conclusions

This chapter outlines ESV's findings and conclusions specifically as they relate to the source of the Garvoc (The Sisters) fire, the engineering analysis of Pole 4's structural integrity, the network asset inspection process, and the steps ESV will take as a result of its investigation.

The source of the Garvoc (The Sisters) fire

The most likely source of the Garvoc (The Sisters) fire was arcing from a high voltage conductor contacting the ground and vegetation at or around 20:49 AEST due to the structural failure of Pole 4.

Engineering analysis

The engineering analysis concluded that the structural failure of Pole 4 was caused by long-term material degradation due to decay and termite infestation, while its 1.2 metre lean was a contributing factor. The long-term material degradation resulted in the timber's reduced compressive and flexural/bending strength, development of a sizeable internal cavity in the region of the point of failure, and the reduced overall capacity that saw the pole's design strength exceeded under the prevailing wind conditions on the day.

Key empirical findings include the following:

- The combined axial bending actions at the failure zone exceeded the pole's design strength by:
  - 7% for the actual wind conditions of 29 metres per second on the day
  - 62% for the ultimate design wind speed of 50 metres per second in accordance with AS/NZS 4676-2000.
- The outer material thickness of Pole 4, which averaged 25 millimetres (varying between 10 millimetres and 40 millimetres), needed to be (at a minimum):
  - 32.5 millimetres to withstand the actual wind conditions of 29 metres per second
  - 60 millimetres to withstand the ultimate design wind speed of 50 metres per second.

Powercor's asset inspection criteria state that poles with less than 30 mm of sound wood are unserviceable. Note that the minimum amount of sound wood calculated for a Mountain Grey Gum to withstand the ultimate design wind speed is 60 mm.

The analysis further suggests that a competent inspection and sound test of the pole in November 2017 is likely to have identified the material degradation that was present when the pole failed.

The network asset inspection process

Records suggest Powercor Australia Limited has been undertaking certain maintenance in accordance with its BMP, which requires that all serviceable poles in HBRA receive a full inspection and a limited inspection on alternating five-yearly cycles (occurring two and a half years apart). ESV's investigation has established the following:

- Powercor Australia Limited's AIM requires a sound test to be undertaken with every inspection (to identify cavities)

- Pole 4 received a pole top inspection on 30 November 2017 (less than four months prior to the pole's failure) and its condition at that time was classified as serviceable
- The asset inspection records for Pole 4 for the last 13 years, which included three full inspections (the last occurring in May 2015), failed to identify a cavity
- It is likely that Pole 4 would have been identified as no longer fit for service had an effective sound test (as specified by Powercor Australia Limited's network asset inspection regime) been conducted effectively.

Next steps

As a result of the Garvoc Fire (The Sisters) investigation, ESV will now initiate a more formal investigation of Powercor Australia Limited's current asset inspection practices as well as confirming the current condition of:

- other poles in the Terang area by auditing poles on the same feeder or in the same area as Pole 4
- reinforced poles generally by auditing the Powercor Australia Limited network.

Appendix A – Weather observations

Warrnambool, Victoria
March 2018 Daily Weather Observations

Australian Government
Bureau of Meteorology

Date	Day	Temps		Rain	Evap	Sun	Max wind gust			9am						3pm					
		Min	Max				Dirn	Spd	Time	Temp	RH	Cld	Dirn	Spd	MSLP	Temp	RH	Cld	Dirn	Spd	MSLP
		°C	°C	mm	mm	hours		km/h	local	°C	%	eighths		km/h	hPa	°C	%	eighths		km/h	hPa
1	Th	13.9	20.3	1.2			SSW	43	16:10	14.8	94		SW	15	1018.3	18.7	66		S	22	1018.4
2	Fr	9.5	27.5	0.2			S	31	15:51	13.1	96		E	7	1015.7	26.1	34		ENE	9	1012.0
3	Sa	11.7	22.8	0			SW	50	14:47	17.5	76		WNW	22	1008.7	20.2	64		SW	31	1010.7
4	Su	8.6	20.1	0.2			SSW	41	13:07	16.5	70		SSW	7	1016.9	19.7	41		SSW	26	1017.2
5	Mo	7.8	21.2	0			SSW	43	13:13	14.2	78		WNW	6	1020.4	19.0	44		S	28	1022.5
6	Tu	11.0	22.2	0			S	54	13:27	16.5	67		SE	22	1026.3	20.3	58		SSE	37	1025.4
7	We	8.8	26.9	0			SSE	35	17:45	15.3	89		ESE	7	1026.0	24.5	52		S	22	1023.8
8	Th	9.2	28.8	0			S	33	14:53	17.1	75		NNE	15	1024.3	27.5	36		SSW	20	1022.9
9	Fr	12.0	31.4	0			SSW	33	15:08	18.2	68		ENE	6	1025.2	30.1	31		SSW	19	1023.3
10	Sa	12.8	36.6	0			NW	39	12:08	19.0	58		NNE	17	1023.3	35.8	13		W	13	1020.8
11	Su	14.5	21.1	0			SSW	44	14:51	18.5	79		SSW	22	1024.2	19.0	59		SSW	30	1025.4
12	Mo	14.7	19.9	0			SSW	44	15:18	15.8	69		SW	24	1024.8	18.8	56		SW	30	1024.0
13	Tu	14.5	21.0	0			SSW	46	13:47	17.5	60		SSW	20	1024.5	19.0	50		SSW	26	1023.6
14	We	12.9	20.6	0			SSW	37	12:24	16.2	64		S	13	1021.2	18.5	53		SSW	22	1018.6
15	Th	8.1	20.1	0			SW	37	13:01	13.8	78		NNW	13	1015.4	17.9	70		WSW	26	1016.1
16	Fr	5.9	23.7	0			NE	31	10:40	12.0	97		NNE	9	1016.3	23.3	41		NNW	15	1012.6
17	Sa	12.0	34.1	0.6			NW	104	20:00	22.0	65		N	19	1009.5	32.8	22		N	46	1004.5
18	Su	12.9	20.2	2.8			W	96	11:15	13.5	80		NW	31	1004.7	19.1	44		W	48	1011.0
19	Mo	10.7	23.2	1.4			NW	65	13:08	15.5	82		NW	37	1013.1	21.4	59		WNW	39	1013.9
20	Tu	13.0	18.9	1.4			SSE	52	15:42	14.1	53		S	28	1027.2	16.5	49		SSE	31	1029.5
21	We	10.4	23.7	0			E	52	10:51	13.8	66		ESE	17	1029.0	22.6	44		E	31	1025.3
22	Th	13.7	31.0	0			ENE	46	08:16	16.5	67		ENE	20	1024.4	30.3	29		N	24	1020.0
23	Fr	14.4	31.4	0			N	50	11:51	20.3	52		NNE	22	1020.1	30.6	26		NNE	24	1015.4
24	Sa	17.1	26.8	6.6			SW	39	03:12	17.6	95		NNE	20	1012.3	25.5	41		SW	15	1009.1
25	Su	14.7	21.1	0.2			W	83	15:05	16.8	87		NW	30	1001.0	20.0	42		WNW	43	998.5
26	Mo	7.6	17.7	8.4			W	70	05:05	13.3	70		WSW	37	1009.1	17.4	53		WSW	39	1011.9
27	Tu	9.1	21.5	0			NNW	50	12:19	10.8	85		NNE	11	1015.8	20.5	41		NNW	28	1012.1
28	We	10.8	22.6	0			WSW	52	12:35	18.1	48		NNW	17	1011.5	20.6	70		SSW	24	1014.3
29	Th	13.2	22.4	0			WSW	48	14:46	14.8	73		NNW	13	1017.3	20.7	47		W	24	1015.3
30	Fr	13.3	21.7	0			SW	52	13:57	15.3	86		NW	20	1015.9	19.6	63		SW	37	1017.3
31	Sa	10.0	20.9	0			SW	39	13:33	12.2	88		N	9	1019.4	19.4	45		SSW	24	1016.7
Statistics for March 2018																					
	Mean	11.6	23.9							15.8	74			17	1018.1	22.4	46			27	1017.2
	Lowest	5.9	17.7							10.8	48		#	6	1001.0	16.5	13		ENE	9	998.5
	Highest	17.1	36.6	8.4			NW	104		22.0	97		#	37	1029.0	35.8	70		W	48	1029.5
	Total			23.0																	

Observations were drawn from Warrnambool Airport NDB {station 090186}

IDCJDW3083.201803 Prepared at 13:01 UTC on 14 Apr 2018

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Mortlake, Victoria
March 2018 Daily Weather Observations

Australian Government
Bureau of Meteorology

Date	Day	Temps		Rain	Evap	Sun	Max wind gust			9am						3pm					
		Min	Max				Dirn	Spd	Time	Temp	RH	Cld	Dirn	Spd	MSLP	Temp	RH	Cld	Dirn	Spd	MSLP
		°C	°C	mm	mm	hours		km/h	local	°C	%	eighths		km/h	hPa	°C	%	eighths		km/h	hPa
1	Th	13.3	22.2	1.0			SSW	37	14:41	14.0	98		S	13	1018.1	21.0	56		SW	15	1017.7
2	Fr	7.9	28.9	0			ENE	22	09:54	14.5	100		NE	9	1015.7	26.2	32		NE	7	1012.1
3	Sa	11.6	24.6	0			SW	46	15:01	18.3	60		WNW	13	1008.7	23.1	50		WSW	28	1009.9
4	Su	9.7	20.8	0			SW	35	13:36	13.1	100			Calm	1016.9	19.8	46		SSW	20	1016.8
5	Mo	4.4	22.0	0			SSW	43	13:42	11.2	100		SSW	2	1020.3	19.6	41		S	20	1021.4
6	Tu	5.1	25.1	0			S	37	15:18	14.8	80		SSE	17	1025.7	24.0	42		S	22	1024.0
7	We	6.3	31.1	0			S	33	16:01	14.4	100		ENE	7	1025.9	30.1	26		SSW	6	1023.2
8	Th	8.2	32.7	0			S	35	16:26	17.9	74		NNE	4	1024.8	31.9	23		S	15	1022.1
9	Fr	9.3	34.9	0			SSW	37	15:46	18.1	75		NNE	2	1025.6	33.2	17		SSW	7	1022.7
10	Sa	12.4	37.7	0			WNW	37	14:02	20.3	46		NNE	9	1023.7	35.8	12		W	17	1020.9
11	Su	12.0	23.6	0			S	39	16:31	18.4	83		SSW	19	1024.1	20.6	54		S	22	1024.4
12	Mo	13.5	20.4	0			SSW	41	13:41	15.2	68		SSW	15	1024.6	18.1	58		SSW	24	1023.6
13	Tu	13.1	21.9	0			SSW	35	14:29	15.3	79		SSW	9	1024.2	20.7	46		SSW	20	1022.7
14	We	13.0	22.9	0			SW	43	14:09	15.5	64		SSE	7	1021.1	22.0	43		SSW	15	1017.6
15	Th	6.4	22.4	0			SW	31	16:22	10.6	95		W	4	1015.4	20.5	51		SSW	20	1015.3
16	Fr	5.5	26.4	0			WNW	35	13:26	10.7	100		NE	6	1016.1	24.4	34		NNW	15	1012.5
17	Sa	10.7	34.0	0			NW	104	20:08	19.9	60		N	17	1010.4	31.1	25		N	46	1005.7
18	Su	12.5	21.1	0.4			WNW	76	11:28	13.0	81		WNW	35	1005.3	19.1	34		WSW	35	1011.0
19	Mo	9.1	23.5	0.2			W	57	12:36	14.9	80		NW	30	1013.9	21.7	53		WNW	31	1013.9
20	Tu	11.7	17.1	3.0			SSE	41	17:10	12.8	72		S	9	1027.0	15.3	53		SSE	28	1028.7
21	We	8.2	23.1	0.2			E	59	09:16	14.9	68		E	30	1028.3	22.4	45		E	35	1025.0
22	Th	13.1	30.8	0			E	50	00:25	15.2	73		ENE	15	1024.8	28.5	31		NNE	11	1020.7
23	Fr	14.1	31.1	0			NNE	46	11:26	18.9	56		NNE	15	1020.8	30.0	27		NNE	26	1015.9
24	Sa	16.7	28.0	13.4			W	44	04:08	17.3	100		NNE	7	1013.3	25.7	42		WNW	9	1009.1
25	Su	15.2	22.6	0			W	85	15:26	16.5	89		NW	30	1001.5	21.0	35		WNW	44	999.2
26	Mo	6.8	17.3	3.0			WSW	59	09:53	11.2	85		W	20	1009.0	15.7	65		W	22	1012.0
27	Tu	6.0	22.2	0			N	35	10:52	9.1	98		NNE	6	1016.4	19.5	42		N	15	1012.5
28	We	9.1	24.7	0			N	46	02:26	19.6	34		WNW	22	1011.6	24.0	51		WSW	15	1013.9
29	Th	12.8	23.4	0			WSW	37	13:11	14.8	73		NW	7	1017.5	21.5	43		WSW	13	1015.0
30	Fr	10.9	22.4	0			SW	43	10:23	14.6	92		WNW	13	1016.0	21.5	49		SW	26	1016.8
31	Sa	6.3	22.6	0			SSW	24	16:11	10.2	100		N	4	1019.3	20.8	38		WNW	11	1016.4
Statistics for March 2018																					
	Mean	10.2	25.2							15.0	80			12	1018.3	23.5	40			20	1016.9
	Lowest	4.4	17.1							9.1	34			Calm	1001.5	15.3	12		SSW	6	999.2
	Highest	16.7	37.7	13.4			NW	104		20.3	100		WNW	35	1028.3	35.8	65		N	46	1028.7
	Total			21.2																	

Observations were drawn from Mortlake Racecourse {station 090176}

IDCJDW3053.201803 Prepared at 13:01 UTC on 14 Apr 2018

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Appendix B - Network asset inspections

Documents and plans relevant to the network asset inspection process include the Powercor Australia Limited:

- Electricity Safety Management Scheme (ESMS)
- Bushfire Mitigation Plan (BMP)
- Asset Management Plan (AMP):
  - Network Asset Maintenance Policy for Inspection of Poles
  - Asset Inspection Manual (AIM).

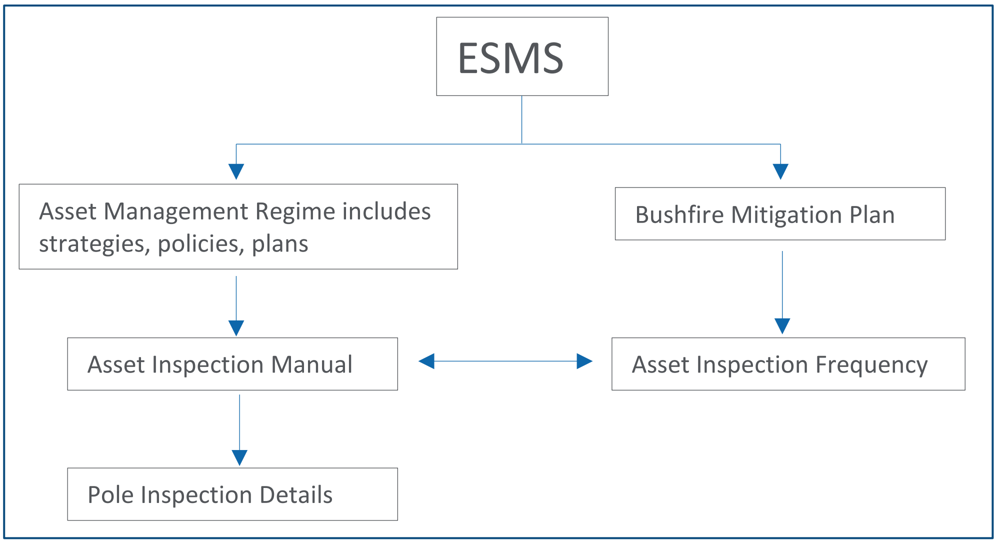
The Asset Inspection Manual is the primary guidance for pole inspection and contains the Work Instruction for Inspection of Poles[34].

Electricity Safety Management Scheme

Powercor Australia Limited operates under an Electricity Safety Management Scheme (ESMS), which complies with the Electricity Safety (Management) Regulations 2010. This scheme directly and indirectly references many areas within the business, including the asset management regime (comprising strategies, policies, and plans), Bushfire Mitigation Plan (which addresses the frequency of asset inspections), and Asset Inspection Manual (which details about what should be inspected). Figure 8 shows the relationships between the ESMS and its various supporting documents and asset strategies.

[34] Powercor Australia Limited, Asset Inspection Manual. Document No: 05-M450, Section G12-WI, Issue 2.8, 08/05/2018

Figure 8: ESMS and supporting documents



Bushfire Mitigation Plan

The BMP requires all serviceable poles in HBRA receive a full inspection and a limited inspection on alternating five-yearly cycles (occurring two and a half years apart), as defined by Section 6.1, Monitoring Asset Condition:

> "1. All serviceable poles shall receive a full inspection within 1 month of their 5 year cyclic inspection date.
>
> 2. All serviceable poles shall be programmed to receive an above ground inspection within 1 month of their 2.5 year cyclic inspection date; this period may be increased to accommodate access issues up to a period of 37 months from last inspection. (Program applicable to all poles scheduled for cyclic inspection from 1/1/2012.)
>
> 3. All Limited Life poles shall receive a full inspection within 1 month of their 2.5 year cyclic inspection date."

The Network Asset Maintenance Policy for Inspection of Poles details the requirements for a full inspection and an above ground inspection.

Asset Management Plan

The AMP for power poles is a high-level document providing information about the types of poles used, and their applications, failure rates and modes[35]. Other documents the AMP references that are more specifically relevant to the management of power poles include the:

- Network Asset Maintenance Policy for Inspection of Poles
- Asset Inspection Manual.

[35] Powercor Australia Limited, Asset Management Plan, Document No. 01-00-M0015 (PAL-AMP-07), Issue 3.0, 23 February 2015, pp. 12,14, 27.

Network Asset Maintenance Policy for Inspection of Poles

This policy describes the two high-level inspection types and their requirements[36]:

- A full inspection of the pole and pole top assets is conducted every five years and requires assessing the condition of the reinforced wood pole and accounting for its classification. It includes excavation, treatment, a pole assessment (including drilling), visual inspection, and a sound test.
- A limited inspection is conducted on an alternating five-yearly cycle (occurring two and a half years after the full inspection). It includes a visual inspection of the pole and pole top assets and a sound test, but excludes excavation, treatment, and pole assessment (drilling).

Both inspection types include the inspection of electrical assets between poles (the AIM provides a more detailed description of what the inspections involve).

Asset Inspection Manual

The AIM provides a more detailed description of the various types of electrical assets and the observations or tests necessary to identify and assess their condition. It also describes the items that need to be identified for approved replacement or modification programs, and sets out criteria for categorising the urgency of remedial maintenance actions and reporting, and information recording requirements.

Powercor Australia Limited's asset inspection regime for poles is broken into three parts: below ground; from ground level to 2 metres above the ground; and from 2 metres above ground to the pole top.

The AIM states that (depending on the type, methods, and techniques used) poles should be subjected to a[37]:

- pole top inspection (involving a single section '2 metres above ground-line to the top of the pole')
- ground level inspection (involving two sections: 'ground-line to 2 metres above', and 'below ground-line').

The SECV inspection and test protocol for reinforced poles specifies the requirements for a sound test[38]. "Strike the pole repeatedly, all round, at all heights to maximum upreach"

[36] Powercor Australia Limited, Network Asset Maintenance Policy for Inspection of Poles, Document No: 05-C001.D-390.

[37] Powercor Australia Limited, Asset Inspection Manual. Document No: 05-M450, Section G12-WI, Issue 2.8, pp 6-7, 27.

[38] State Electricity Commission of Victoria. Wood Poles Inspection of RFD Staked Pole Test Procedure VX9/7020/108/6.

Appendix C - Pole 4 asset inspection records

Pole classification

Records provided by Powercor Australia Limited show that:

- the pole was classified as a wood pole, durability class 3, species GG - Mountain Grey Gum
- Mountain Grey Gum is classified as Strength Group 2 (S2).

Inspection record

Since 2010, the pole was fully inspected every five years (+/-6 months) and a limited inspection was conducted on an alternating five-yearly cycle (occurring two and a half years apart). Records show the following inspections occurred:

- 30/11/2017 - pole top inspection
- 15/05/2015 - full inspection, remaining sound wood measurement 50 millimetres
- 05/12/2012 - pole top inspection
- 10/05/2010 - full inspection, remaining sound wood measurement 100 millimetres
- 11/05/2005 - full inspection, remaining sound wood measurement 70 millimetres.

This inspection regime aligns with Powercor Australia Limited's BMP.

The records show that on 30 November 2017 the pole was classified as serviceable and on 14 May 2015 the pole was assessed as being inspected and no further action was required.

Powercor Australia Limited considers a pole to be unserviceable if it has less than 30 millimetres of sound wood irrespective of species.

Analysis of the asset inspection regime

All inspections are required to include a sound test to identify cavities (loss of material). If undertaken correctly, the test will enable the inspector to identify a sizeable cavity.

In this respect, the results from the Test 5, the condition assessment of a timber section in accordance with AS 4349.3-2010, Timber Pest Inspections (Test 5) stated that[39]:

> "The detection of biodeterioration in poles, as practised by industry, typically revolves around visual inspection and tapping to elicit resonance (sounding). Though it is not easily described, the change of sound resulting from tapping near hollows by termites is, with experience, typically distinctive. A solid pole, when struck, will 'ring' (resonate) and cause a rebound (bounce) of the striking tool, while a strongly hollowed timber tends to give a dull 'thud' with reduced or little detectable rebound.

[39] Dr. Ewart, D. (2018). Inspection of Pole E-26435, The Sisters. Melbourne.

> The pole was significantly degraded, and in my opinion, based on the visual evidence, had been so for many years. A competent inspection of the pole in 2017 would in my opinion, have found virtually the same evidence of degradation as present at failure in March 2018, and as observed by me on 18 May 2018. Sounding of the pole would have been able to indicate a loss of integrity above the top of the bracing."

ESV cannot establish whether the sound inspection of Pole 4 was carried out at the last inspection however it is ESV's opinion that a competent sound test of the pole in November 2017 is likely to have identified the cavity.

Powercor Australia Limited failed to identify that Pole 4 had a substantive internal cavity which compromised the pole even though specific tests (sound test) exist to identify internal cavities.

Asset inspection record analysis

Analysing Powercor Australia Limited's asset inspection records[40] revealed that between 2010 and 2015 the amount of sound wood deteriorated from 100 millimetres to 50 millimetres, which is:

- a 50% decrease in the amount of sound wood over a five-year period
- approaching the 30 millimetre point at which the pole will be classified as unserviceable.[41]

Powercor Australia Limited operates a Report by Exception system (which does not facilitate data collection potentially used as the basis for asset management) that only reports issues, with the exception that the amount of sound wood is recorded at every full inspection.

Powercor Australia Limited records do not show identification of a cavity during the last November 2017 inspection (less than 4 months prior to the pole's failure).

Pole condition and classification

The Powercor Australia Limited's 'Asset Management Plan for Poles' identifies Mountain Grey Gum (Code GG) as a Strength Group 2 (S2) pole[42][43]. However, the testing and assessment of Pole 4 classified it as Strength Group 3 (S3)[44].

Figure 9 shows the Pole 4 cavity and the termites found during testing.

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[40] Energy Safe Victoria, Pole 4 Asset Inspection Records (Compilation), 2018, Energy Safe Victoria, Melbourne.

[41] Refer to "Testing and Assessment Results" below which show that the minimum calculated thickness for the pole to survive the maximum wind condition of 180 km/h is 60 mm.

[42] Powercor Australia Limited. Asset Management Plan for Poles. Table 3.2. Document Number 01-00-M0010.

[43] Strength groups are based on the characteristic strength of timbers, with the Australian Standard specifying seven strength groups for unseasoned timbers (S1 – S7), S1 being the strongest.

[44] Rule, Rob (2018), Inspection of Failed Power Pole 4 Sparrow Spur Inspection of Failed Power Pole 4 Sparrow Spur, Timber Training Creswick Limited. Creswick.

Figure 9: Pole 4 cavity and termite infestation

Appendix D – Testing and assessment results

ESV engaged FMG Engineering to undertake an engineering investigation into the failure/collapse of Pole 4. FMG Engineering developed a series of six separate types of tests and inspections to establish the condition of the pole at the time of its failure and the possible causes and contributing factors.

Test 1: visual inspection

The visual inspection[45] identified that the pole was 10.5 metres in length, had been embedded in the ground to 1.5 metres, and the structural failure point was 1.5 metres above ground.

A visual assessment of the photograph of the pole before it failed showed three overhead conductors (with other evidence indicating that each conductor comprised 3 strands of 2.75 millimetre wire). It also showed there was a lean of 1.2 metres (a column eccentricity of 1.2 metres with respect to the point of failure).

The visual assessment of the pole identified the following:

- The pole was broken into three separate sections. The bottom section, approximately 3 metres in length, was the base of the pole and was unaffected by the fire. The top section was the head of the pole and its lower edge was fire affected. The central section (between the base and the head of the pole) had been extensively and significantly charred.
- The measured lengths of the sections of the pole indicate that its total length was approximately 10.5 metres. The embedded (in-ground) depth was measured at approximately 1.5 metres, which equates to a length of approximately 9 metres above ground.
- The structural failure zone is located at the upper region of the salvaged bottom section, approximately 3 metres above the base of the pole coinciding with the upper section of the (removed) galvanised steel reinforcing stakes, which are 3 metres long.
- There was no evidence of fire damage to the timber within the structural failure zone.
- There is evidence of extensive timbre rot/decay within the structural failure zone and beyond.
- The diameter of the pole was measured to be approximately:
  - 320 millimetres at its base
  - 200 millimetres at its head
  - 250 millimetres at/near the structural failure zone.
- The pole was significantly hollowed at the region of structural failure and beyond as a result of timbre rot/decay, which has affected the interior regions of the pole in this region and beyond.
- The average diameter of the structural failure zone was measured at 190 millimetres.
- The measured outer material thickness of the failure zone ranged between 10 millimetres and 40 millimetres, which equates to an average outer thickness of 25 millimetres.

[45] Eracleous, E. (2018). Engineering Investigation Report. The Sparrow Spur – Pole 4 (LIS #20675). FMG Reference S40461 – 261138, FMG Engineering, Melbourne.

- Sections of the outer material thickness at the failure zone appear to also be affected by decay.

Test 2: species identification

Pole 4 is made from Eucalyptus cypellocarpa, commonly known as Mountain Grey Gum[46]. Natural durability ratings (as per AS 5604 -2005 (R2016) Timber - Natural Durability Ratings) give this species an in-ground durability rating of 3, with a probable life expectancy of 5 to 15 years, making the timber unsuitable for use for power/utility poles without treatment of the sapwood[47].

Test 3: strength group testing

This species is listed as strength group S3, SD2[47].

Test 4: visual stress-grading

AS3818.1 Timber - Heavy structural products - Visually Graded Part 1: General Requirements lists the following properties for the Mountain Grey Gum species[9]:

- Strength Group - S3, SD2
- Joint Group - J2, JD2.

The timber strength group corresponding to the subject pole was determined as S3, which is equivalent to an F22 stress grade (according to AS/NZS4676-2000, Table 4.3.1).

Suitable uses include railway sleepers, piles, and utility poles (with appropriate preservative treatment).

AS2082-2007, Timber – Hardwood – Visually Stress-Graded for Structural Purposes lists further properties of this species as[9]:

- lyctid[48] susceptible
- having a density at 12% 860kg/m3.

The pole was unable to be graded based on AS 2082-2007 (due to being a round section).

The pole was able to be graded against AS 3818.11-2009 Timber – heavy structural products – Visually graded utility poles. The results of the grading are as follows:

- Straightness - the pole pieces show no obvious deviation and appear to meet the straightness requirements of select grade.
- Barrel checks rating - the pieces inspected show barrel checks in excess of 6 millimetres. This is expected in a pole of this age.
- Spiral grain - there was no evidence of spiral grain in the pieces inspected.
- Decay - the pole showed extensive rot well above the ground line. Given its age, this is probably secondary decay, which has developed from a breach of the preservative treatment.
- Mechanical Damage - this was restricted to the fixings and fittings associated with positioning the crossarm and bracings.

Test 5: condition assessment

The condition assessment of a timber section in accordance with AS 4349.3-2010, Timber Pest Inspections, involved assessing the pole for evidence of timber pests, the existence of visually

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[46] Illic, Jugo. (2018). Wood Identification Results. Melbourne: Know Your Wood. Melbourne.

[47] Rule, Rob (2018), Inspection of Failed Power Pole 4 Sparrow Spur Inspection of Failed Power Pole 4 Sparrow Spur, Timber Training Creswick Limited. Creswick.

[48] Pests that attack the sapwood sections of hardwood timbers.

observable damage caused by timber pests, susceptibility to timber pests, and any further investigations required[49]. A summary of the key observations is as follows:

- Pole 4 shows clear signs of decay and was significantly hollowed, with the hollowing extending well above the top of the stakes/steel reinforcement (possibly by more than 2 metres).
- Pole 4 was infested with termites above its base, below which the pole was subject to heavy soil moisture causing it to be damp, which deterred termite activity.
- Visual inspection and tapping (sounding) showed the extent of the pole's hollowing, which would have been similarly detectable well above the plane of failure, and indicated the loss of integrity above the stakes/steel reinforcement.
- The pole was significantly degraded and likely had been that way for many years. A competent inspection of the pole in 2017 would likely have found the same evidence of degradation present at failure in March 2018 (and observed during testing in May 2018).

When the pole was cut for testing, active termites were found to be infecting the pole. Figure 9 shows the Pole 4 cavity and the termites found.

Test 6: laboratory testing

Laboratory testing of samples of wood from Pole 4 established that the[50]:

- average moisture content was determined to be 63% of the final weight of the dried samples
- average basic density of timber was 637.7 kg/m³
- design bending strength was measured as 58MPa; the test result of the specimen taken near the pole's failure zone was also 58MPa (the bending strength that would normally be adopted for design purposes is 65MPA for stress grade F22/strength group S3)
- design compressive strength was measured as 36MPa; the design compressive strength of the specimen taken near the pole's failure zone was measured as 31.5MPa (the compressive strength that would normally be adopted for design purposes is 50Mpa for stress grade F22/strength group S3).

Results analysis

Design capacity

The assessment conditions considered that the diameter of pole at the structural failure zone was 250 millimetres, with a 200 millimetre central cavity, and an average outer material thickness of 25 millimetres and varying between 10 millimetres and 40 millimetres.

Table 2 compares the expected Design Bending Strength and the Design Compressive Strength for a 54-year-old pole with the actual values determined via testing.

Table 2: expected and actual results for Design Bending Strength and Design Compressive Strength of Pole 4

Design condition	Design Bending Strength Clause 4.3.4.2 of AS/NZS 4676-2000[1]	Design Compressive Strength Clause 4.3.4.4 of AS/NZS 4676-2000
Expected	ØM = 61 kNm	$ØN_c$ = 56.2 kN
Actual	ØM = 40.2 kNm	$ØN_c$ = 15.9 kN
	1. Australian Standard AS 4676-2000 Structural Design Requirements For Utility Services Poles.	

[49] Dr. Ewart, D. (2018). Inspection of Pole LIS # 26435, The Sisters. Melbourne

[50] Breitinger, H. (2018). Small Clear Tests on Eucalyptus Cypellocarpa (Mountain Grey Gum) Power Pole, Breitinger Consulting, Maryborough.

FMG Engineering determined that the pole's:

- Design Bending Strength is approximately 64% of the expected value (36% lower than expected)
- Design Compressive Strength is approximately is 27% of the expected value (73% lower than expected).

As such, the pole's actual design strength is significantly lower than the expected design strength, which makes allowance for the anticipated natural degradation over a 54-year period.

Design actions

Table 3 lists the design actions that were calculated:

- in accordance with AS/NZS 1170.0-2000, AS/NZS 1170.1-2002, AS/NZS 1170.2-2002 and AS/NZS 4676-2000
- for the maximum design wind speed of 50 metres per second (180 kilometres per hour) and for the actual wind speed of 29 metres per second (104 kilometres per hour) recorded by the BOM.

Table 3: design actions for actual and maximum design wind speeds

Wind speed	Design Bending Moment	Design Compressive Force
50 m/s	M* = 44.6 kNm	N* = 8.2 kN
29 m/s	M* = 22.4 kNm	8.2 kN

FMG Engineering determined the following:

- The combined axial-bending design strength of the pole is exceeded by:
  - 7% for the actual wind conditions of 29 metres per second
  - 62% for the ultimate design wind speed of 50 metres per second.
- The outer material thickness of the pole required to withstand wind speeds of:
  - 29 metres per second is 32.5 millimetres
  - 50 metres per second is 60 millimetres.

Pole 4 had an average outer material thickness of 25 millimetres (varying between 10 millimetres and 40 millimetres). This thickness is less than the minimum thickness required to withstand the 104 kilometres per hour (29 metres per second) wind on 17 March 2018 and significantly less than required to withstand the maximum design wind speed of 180 kilometres per hour (50 metres per second).

The FMG Engineering report stated that the design strength of Pole 4 would have been exceeded even further if a more refined analysis of the cross-section had been adopted.

The cause of the structural failure

FMG Engineering delivered the flowing findings:

- The structural failure/collapse of the subject timber pole occurred as a result of a significant reduction in the compressive and flexural/bending strength of the section at the region of the failure zone
- The reduced strength appears to have been caused by long-term material degradation of the timber (from rot/decay) at the failure zone, resulting in a reduction in the material strength properties of the timber, but more critically the development of a sizeable internal cavity that resulted in a significant reduction in the effective cross sectional area at this location to resist the required flexural-compressive stresses

- Based on the design assessment, the overall design capacity/strength of the timber pole at the failure zone is shown to be exceeded by 7% when subjected to the expected ‘actual’ wind speeds of 29 metres per second recorded by the BOM
- While the design assessment is based on ‘reasonable assumptions’ (as made by the analyst) about the expected condition and cross-sectional area of the timber pole at the failure zone, the actual conditions at the failure zone at the moment of failure are unknown and cannot be definitively confirmed. As a result, it is possible the pole’s strength may have been even lower than calculated. There is also evidence of decay of the remaining outer material thickness at the failure zone, which is expected to have reduced the strength of the pole even more
- Pole 4 should have been able to withstand wind speeds significantly greater than the wind speeds on the day of the failure, and utility poles in the immediate area should have sufficient strength to withstand wind speeds of at least 50 metres per second (180 kilometres per hour)
- The proximate cause of the structural failure/collapse is related to the long-term material degradation (timber rot/decay) at the failure zone, which resulted in a significant reduction in the structural capacity of the pole to resist the wind loading conditions
- The 1.2 metre lean of the pole was a contributing factor.