TransGrid Revised Revenue Proposal 2018-23

Review of 132kV cable MTTR assumptions for Powering Sydney's Future project

Report to

Australian Energy Regulator

from

Energy Market Consulting associates

April 2018

This report has been prepared to assist the Australian Energy Regulator (AER) with a particular aspect of its determination of the appropriate revenues to be applied to the prescribed transmission services of TransGrid from 1st July 2018 to 30th June 2023. The AER's determination is conducted in accordance with its responsibilities under the National Electricity Rules (NER). This report covers a particular and limited scope as defined by the AER and should not be read as a comprehensive assessment of proposed expenditure that has been conducted making use of all available assessment methods.

This report relies on information provided to EMCa by TransGrid and Ausgrid. EMCa disclaims liability for any errors or omissions, for the validity of information provided to EMCa by other parties, for the use of any information in this report by any party other than the AER and for the use of this report for any purpose other than the intended purpose.

This report is not intended to be used to support business cases or business investment decisions nor is this report intended to be read as an interpretation of the application of the NER or other legal instruments. EMCa's opinions in this report include considerations of materiality to the requirements of the AER and opinions stated or inferred in this report should be read in relation to this over-arching purpose.

Except where specifically noted, this report was prepared based on information provided by AER staff prior to 16 March 2018 and any information provided subsequent to this time may not have been taken into account.

Energy Market Consulting associates
802 / 75 Miller St, North Sydney NSW 2060

and

Level 1, Suite 2 572 Hay St, Perth WA 6000
AUSTRALIA

Email: **contact@emca.com.au**
Web: **www.emca.com.au**

About EMCa

Energy Market Consulting associates (EMCa) is a niche firm, established in 2002 and specialising in the policy, strategy, implementation and operation of energy markets and related network management, access and regulatory arrangements. EMCa combines senior energy economic and regulatory management consulting experience with the experience of senior managers with engineering/technical backgrounds in the electricity and gas sectors.

Authorship

Prepared by:	Gavin Forrest, Richard Gibbons and Paul Sell with input from Mark de Laeter.
Quality approved by:	Paul Sell
Date saved:	30/04/2018 4:40 p.m.
Version:	FINAL

Table of Contents

[This page intentionally blank]

Executive summary

Purpose of this report

1. The purpose of this report is to provide the AER with an expert opinion on the reasonableness of the mean time to repair (MTTR) assumptions of 132kV cables for the Powering Sydney's Future (PSF) project in TransGrid's Revised Revenue Proposal (RRP) submission.

Scope of work

2. We have been requested to assess the reasonableness of the method used by Ausgrid to determine its MTTR of 1.86 weeks (or approximately 13 days) and to form an opinion of the MTTR values assumed for its fleet of 132kV oil filled cables. The values of MTTR are used in determining cable unavailability, as an input to the business case and timing of TransGrid's PSF project.

3. The assessment contained in this report is intended to assist the AER in its own analysis of the input assumptions relevant to consideration of the PSF project and capex allowance, as an input to its Final Decision on TransGrid's revenue requirements. Accordingly, we have not reviewed how Ausgrid or TransGrid has applied the estimates of MTTR to determine cable unavailability as part of its justification of the PSF project.

Our approach

4. We have engaged a cable expert to review the analysis provided in this report, and to provide an expert opinion on a reasonable estimate of MTTR.

5. We have undertaken our assessment by first considering the failure frequency assumptions, and how Ausgrid has applied its assumptions in its calculation of a frequency weighted MTTR to its own failure data. We have then considered the repair time assumptions used upon by Ausgrid, to independently consider reasonable estimates of outage times for different types of cable faults.

Assessment of failure frequency assumptions

6. We have reviewed the cable risk model provided by Ausgrid, and the failure event data allocated to the 66 fault event types comprised within it. We have also reviewed the methodology Ausgrid applied to develop its estimate of frequency weighted

MTTR, including its allocation of fault types with unknown causes to fault events with known causes.

7. We consider that the method applied by Ausgrid to allocate the failure events recorded in its corporate system is likely to lead to the calculation of a higher weighted average MTTR value than Ausgrid has actually incurred. Corrections to the fault event data are required to remove any bias, and when applied result in an estimate of MTTR of approximately 1 to 1.5 weeks.

Assessment of Ausgrid's repair and outage time assumptions

8. We have independently reviewed the repair and outage times allocated to the fault events assigned to Ausgrid's corrective repair (M2) events, based on its historical records. For more than half of the corrective repair fault event types, our experience-based estimate of required outage time is lower than that proposed by Ausgrid.

9. When we apply the lower outage times and frequency data proposed by Ausgrid (unadjusted by EMCa), to the frequency weighted methodology, the calculated estimate of MTTR is approximately 0.5 to 0.9 weeks. The outage times applied exclude several factors such as uncertainty and third-party approvals, and once incorporated will increase the reasonable estimate of MTTR. The determination of these factors is directly related to Ausgrid's operational practices and experience of its population of oil-filled cables. We would expect that the addition of these factors would increase the estimate of MTTR by a material amount.

Assessment of a reasonable estimate of MTTR

10. We have reviewed the frequency of events and outage time assumptions separately in our analysis. We have nominated several factors that are likely to impact the individual assumptions used by Ausgrid and corresponding estimate of MTTR.

11. When we incorporate the lower outage times developed by our cable expert to the corrections made to Ausgrid's frequency data, and apply these adjustments to the frequency weighted methodology, the calculated estimate of MTTR is approximately 0.3 to 0.4 weeks. As stated above, factors relating to uncertainty and third-party approvals are not included in this estimate and when included, will increase the estimate of MTTR to a value approaching 1 week.

12. We consider that a MTTR of 1 day is not a reasonable estimate of the MTTR based on the data provided by Ausgrid, and which is the same data from which Ausgrid has based its predictive cable failure model. A MTTR at this level could only be indicated, from the data provided, by removal of a significant amount of failure event data that Ausgrid has collected, and on the balance of probability, we consider that the majority of this data is likely to represent an outage event of some kind in its network. Ausgrid has stated that its data is not 100% correct, however we consider that corrections to this data on a reasonable basis would not reduce the calculated frequency weighted MTTR to a level approaching 0.1 weeks (or 1 day).

13. Similarly, based on the application of a reasonable set of assumptions, we were not able to reproduce a MTTR approaching a value of 2 weeks as proposed by Ausgrid and used by TransGrid in its business case modelling.

1 Introduction

1.1 Purpose of this report

14. The purpose of this report is to provide the AER with an independent expert opinion on the reasonableness of the mean time to repair (MTTR) assumptions of 132kV cables for the Powering Sydney's Future (PSF) project in TransGrid's Revised Revenue Proposal (RRP) submission. TransGrid has relied on Ausgrid's estimate of MTTR in establishing the cable unavailability as an input to the business case and timing of its PSF project.

1.2 Scope of requested work

15. The assessment contained in this report is intended to assist the AER in its own analysis of the input assumptions relevant to consideration of the PSF project and capex allowance, as an input to its Final Decision on TransGrid's revenue requirements.

16. In its response to the Draft Decision, TransGrid acknowledges the AER's weighted average approach to calculating mean time to repair (MTTR). However, TransGrid has provided new data on fault repair times, and when applied to the weighted average approach, this results in a higher MTTR than calculated by the AER and also higher than in TransGrid's initial Revenue Proposal.

17. We have been asked to provide advice which comprises:

    - Assessment of reasonableness of the method used by Ausgrid to allocate unknown fault types to repair categories; and whether actual available outage data is suitable to cross check cable repair times; and
    - An opinion on the MTTR of 132 kV oil filled cables.

1.3 Our approach

18. In undertaking our review, we:

- completed a desktop review of the information provided by TransGrid and Ausgrid since the Draft Decision – including relevant information in TransGrid's RRP, its supporting information, and responses to requests for information from the AER; and
- completed a desktop review of the information provided by TransGrid and Ausgrid during the RP phase that we assessed as part of our initial RP report.

19. The limited nature of our review does not extend to advising on all options and alternatives that may be reasonably considered by TransGrid, or on all parts of the PSF project or associated capital expenditure forecast. Accordingly, our conclusions in this report should not be interpreted as overarching conclusions on the viability (or otherwise) of TransGrid's proposed PSF project.

1.4 Structure of this report

20. Our main findings are summarised in the Executive Summary at the beginning of this report.

21. In the subsequent three sections, we describe our assessment and conclusions regarding TransGrid's new information in its RRP:

    - In Section 2, we provide a summary of the AER's Draft Decision and TransGrid's revised methodology for calculating frequency weighted MTTR submitted as a part of its RRP;
    - In Section 3, we provide our assessment of the frequency of events used by Ausgrid in its revised methodology for calculating its frequency weighted cable MTTR; and
    - In Section 4, we provide our assessment of Ausgrid's outage time assumptions by fault type. We present our own estimates based on Ausgrid's fault event types, and our estimation of a reasonable MTTR value, taking account of both failure frequency assumptions and outage assumptions by fault type.

22. We include our opinion letter from our cable expert as Appendix A.

23. In Appendix B we provide details of the factors that influence the determination of cable outage times, and that we have used in our estimates of reasonable outage times included in section 4.

24. In Appendix C we have included a case example from the oil-filled cable failure repair times associated with the 1998 blackouts of Auckland CBD.

1.5 Information sources

25. We have examined relevant documents provided by TransGrid to the AER as part of its RRP submission, and in response to requests for further information from the AER. These documents are referenced directly where they are relevant to our findings.

26. In providing our letter of opinion, additional reference materials have been cited where they have been relied upon in providing our advice.

2 Background

27. This section provides a high-level overview of Ausgrid's approach to calculating its cable MTTR values, and how this compares with the AER's Draft Decision and the revised methodology included with TransGrid's RRP.

2.1 Overview of Ausgrid's approach to calculating MTTR

28. Ausgrid's approach for determining cable unavailability, as described in TransGrid's initial RP, was summarised in our initial RP report. The AER has requested that we consider only the changes that Ausgrid has proposed to its derivation of MTTR, as described in TransGrid's RRP.

29. Ausgrid has eight 132kV oil-filled cables that supply the inner Sydney area, including the CBD, and which are relevant to TransGrid's modelling of the PSF project. Ausgrid states that these cables are prone to leaking oil through a large range of failure modes. The MTTR for these eight cables is derived from data from Ausgrid's total population of 132kV oil filled cables.

Failure modes

30. As outlined in our initial RP report, Ausgrid has identified multiple failure modes and causes.[1] This includes classification of 66 individual failure modes in its failure rate modelling. Ausgrid subsequently defines cable failures in three mode types (or groups): corrective repair (M2), breakdown (M3), or third-party damage (M5). Ausgrid has not provided a definition of M1 events.

31. Corrective (M2) cable repairs (or minor failures) can be planned or unplanned and are typically associated with defects identified through inspection, testing and monitoring of cables. Where the corrective repair can be completed in a planned outage, the MTTR has been set to zero. Alternatively, where additional time is required beyond the planned outage or where a specific outage is required then a (non-zero) MTTR value is assigned. Breakdown repairs (M3) or major failures, and

---

[1] EMCa - Review of aspects of TransGrid s forecast capital expenditure - June 2017

third-party damage (M5) failures, are unplanned events and result in the requirement for an outage to repair.

Failure events

32. Ausgrid has provided a cable risk model[2] that includes information on 1,200 failures/defects over the period 2009 to 2015. The model includes: notification type (M1, M2, M3, M5); cable attributes; failure and cause of event and failure year. The duration of the repair time, or outage time (if any) is not included in Ausgrid's cable risk model.

33. The failure events are categories according to the notification type and year as shown in the table below.

Table 1: *Distribution of failure notification in Ausgrid's cable risk model*

	2009	2010	2011	2012	2013	2014	2015	Total
M1	9	2	3	3	2	13	1	33
M2	286	49	61	362	144	69	165	1,136
M3	1	2	3	3	3	6	2	20
M5	5	1	1	2		1	1	11
Total	301	54	68	370	149	89	169	1,200

Source: Ausgrid cable risk model

34. As can be seen from the table above, a total of 1,136 events are assigned to corrective failures (M2). The corrective failures have the largest impact on the derivation of the cable unavailability calculation, and we have therefore focussed our assessment on these items.

MTTR

35. In its original cable risk model included in TransGrid's RP submission, Ausgrid relied on assessment of individual repair times for each cable failure type to derive the MTTR values.[3] It did this by averaging the individual repair times for each of the 66 fault types assigned to the three notification types.

36. The MTTR values derived by Ausgrid, and relied upon by TransGrid, were 1.06 weeks for corrective repair (M2), 7.0 weeks for breakdown (M3) and 5.5 weeks for third party damage (M5).

2.2 Overview of AER's Draft Decision

37. In the Draft Decision, the AER did not accept Ausgrid's methodology, referring to a number of concerns:

- *"..failure rates of one type of outage are influenced by other outage types. This becomes problematic when considering the failure data series relied on.*

---

[2] TransGrid-IR030-Ausgrid-Q33 Cable Risk Model REV2_TRANSGRID v1_3_FINAL (6yr Failure Data) May 2017-20170526-CONFIDENTIAL

[3] Referred to as 'AUSGRID OIL CABLE MODEL MEAN TIME TO REPAIR (MTTR) PARAMETERS'

Notably, the breakdown failure type is approximately 1 per cent of the observed the number of corrective outages…", [4] and

- "*While, we agree with excluding planned events from the unavailability calculations, we are concerned that Ausgrid's method does not adequately remove their impact from the modelling.*" [5]

38. The AER was not convinced by Ausgrid's approach to calculate MTTR and substituted an alternate methodology based on a weighted average method. AER's weighted average method significantly increased the number of events assigned a zero outage time, reduced the estimates of non-zero repair time and was based on an alternate data set of 939 failure events.

39. These adjustments by AER, led to an alternative calculation of MTTR for corrective events (M2) of 0.078 weeks.[6]

2.3 Overview of TransGrid's revised proposal

40. In its RRP, TransGrid states that[7] "*The AER also presented an alternative view regarding the use of a weighted average to calculate the average mean time to repair (MTTR) of cable faults. We did not apply this approach during the initial analysis due to data availability. Further review and data consolidation has now allowed us to apply it*."

41. In specifically addressing the AER's concerns in regard to cable unavailability[8] for the PSF project, TransGrid state that[9] *"The AER rejected the inclusion of corrective outages in cable unavailability rates because they include events within the control of Ausgrid. The AER's own consultants, EMCa, found the approach reasonable and it is unclear why the AER has disagreed with them* ***. TransGrid and Ausgrid maintain that the cable availability modelling conducted by Ausgrid is a robust and reasonable basis for the forecast.***"

42. In its RRP, TransGrid describe the cable unavailability assumptions as[10] *"…based upon outage histories (to determine outage frequencies) and a study of the failure types (to determine mean time to repair). The resulting annual "cable unavailability" assumptions are important factors in the calculations of unserved energy*".

43. We note that the AER was also concerned by Ausgrid's treatment of planned outages in its cable unavailability calculation. In response, TransGrid state that[11] "*Even if 60% of planned corrective outages were moved to a shoulder period and*

---

[4] AER Draft Decision, Attachment 6 − Capital expenditure | TransGrid transmission draft determination 2018–23, 6-111 and 6-112

[5] Ibid, page 6-113

[6] AER Draft Decision, Attachment 6 − Capital expenditure | TransGrid transmission draft determination 2018–23

[7] TransGrid's RRP page 58

[8] Referred to in the RRP as cable 'availability'

[9] TransGrid's RRP, page 53. Emphasis included by TransGrid.

[10] TransGrid's RRP, page 58

[11] Ibid

the alternatively derived MTTR values were applied, sensitivity analysis shows that the optimal timing of PSF does not change."

44. TransGrid has included revised estimates for MTTR, based on a frequency weighted MTTR for corrective events (M2) of 1.89 weeks. Ausgrid has not proposed any change to the methodology or values assigned to breakdown repairs (M3) or third-party damage (M5) events.

2.4 Summary

45. We review the methodology and reasonableness of the business rules applied by Ausgrid to its cable failure data, and the steps it took to verify its approach in Sections 3 and 4. We have structured our assessment to consider the factors described by TransGrid for each fault type as: (i) frequency of outages, and (ii) the mean time to repair.

3 Assessment of frequency of events in cable MTTR assumptions

3.1 Introduction

46. In this section, we describe our assessment of the information provided in TransGrid's RRP and supporting information to justify the frequency of fault events relied upon in calculated the frequency weighted MTTR for Ausgrid 132kV cables.

3.2 Our assessment of cable MTTR

Cable unavailability

47. In response to a request for information during assessment of TransGrid's RP, Ausgrid describe the calculation of cable unavailability as[12] "*Ausgrid employs an age and condition-based model to forecast individual oil (SCFF) feeder cable failures using historical failure information based on the Crow-AMSAA modelling technique. A generic population failure forecasting model is adjusted to produce individual feeder parameters based on serving Insulation Resistance (IR) and oil leak conditional information.*"

48. In our initial RP report, we describe the methodology and input assumptions that relate to the application of this methodology by Ausgrid. In summary, the calculation of cable unavailability is calculated used the failure rate and MTTR for each of the failure categories of corrective repair (M2), breakdown (M3) and third-party damage (M5). Based on the example of its cable unavailability calculation provided by Ausgrid, the failure rates and therefore the cable unavailability due to breakdowns

---

[12] Ausgrid response to AER information request 25 – Supply to inner Sydney and CBD v1.1

and third-party damage are much lower than for corrective repairs.[13] We have therefore focussed our assessment on consideration of the assumptions for corrective repair events (M2).

Estimates of cable repair time

49. Ausgrid has assigned an estimate of repair times for each failure mode. In response to a request for information during assessment of TransGrid's RP, Ausgrid state that[14] "*These timeframes were determined through consultation with Ausgrid oil cable engineering specialists based on their extensive experience with these assets. These timeframes are an 'on average' estimate of repair times because the time needed to undertake any repair varies considerably across the population due to a number of issues...*"

50. Ausgrid has not made any adjustments to its experience-based estimates of repair time for individual failure events that were included as part of TransGrid's initial RP submission. In this section we have focussed on Ausgrid's treatment of the frequency of events. In section 4, we comment on the individual repair times.

Cable failure data

51. Ausgrid's cable data is extracted from its corporate system (SAP) and comprises over 1,200 lines of information, one entry for each failure/defect event for the period 2009 to 2015. A subset of the dataset corresponding with each of the M2, or M3 or M5 notification types is used to determine separate failure rates for each of the corresponding failure mode types.

52. In our initial RP report, we stated that[15] "*Ausgrid has advised that its historical data is not 100% complete*" and *"There are also apparent inconsistencies between cable failure data spreadsheets. Ausgrid advises that it has sought to account for these issues with historical data by relying on SAP notification/defect data as the basis for defect intensity.*"

53. Whilst it was not within our scope of review to undertake an audit of Ausgrid's data, we had concerns regarding the robustness of the data relied upon by Ausgrid and the conclusions that could be reasonably drawn in determining cable unavailability. In our initial RP report, we stated that[16] "*The duration for which the cable was out of service (if at all) is not included in Ausgrid's cable risk model. The 1,200 failures/defects include a significant number of events which appear not to require a cable outage to rectify*."

54. For example, in response to a request for information during assessment of TransGrid's RP, Ausgrid referred to a cable failure of Feeder 91X/2 recorded in its corporate system (SAP) for a corrective failure due to low oil pressure caused by an oil leak in 2015. In describing this event, Ausgrid explains that in response to the

---

[13] For the feeder 91X/2, the cable unavailability due to M2 is calculated as 0.0645, whereas the total unavailability for all categories (M2, M3, M5) is 0.0795

[14] Ausgrid response to AER information request 25 – Supply to inner Sydney and CBD v1.1, page 11

[15] EMCa – Review of aspects of TransGrid's forecast capital expenditure – June 2017, page 97

[16] Ibid, page 100

alarm, it took steps to restore the oil pressure, such that[17] "*In this instance, the pressure was restored and the cable was not taken out of service.*"

55. In response to a request for information during assessment of TransGrid's RRP, Ausgrid stated that its[18] *"..lack of defect rectification details associated with outages was a function of historic operational reporting practices occurring up to 7 years before the model was developed. Notwithstanding this, the vast majority of defects captured in the sample period, by their nature, required an outage to rectify.*"

56. We have reviewed these claims in our assessment of the cable failure data, and Ausgrid's revised methodology for calculation of a frequency weighted MTTR.

Treatment of failure frequency

57. In response to a request for information during assessment of TransGrid's RRP, Ausgrid has described its methodology for the calculation of its frequency weighted corrective repair (M2) MTTR as[19] "*based on the unplanned repair times associated with the historic failure data for Ausgrid's 132kV oil-filled underground cables. The analysis for the M2 (corrective) unplanned MTTR has been based on data for 1,136 failures (from Ausgrid's asset management system) of which 361 incidents had an identified cause reported.*"

58. In evaluating the AER's Draft Decision, Ausgrid has revised its methodology for calculating its MTTR[20] *"…by applying a similar frequency weighted calculation utilising the full set of failure information previously provided in the Cable Risk Model.*" As indicated above, Ausgrid has relied on 1,136 failure events associated with corrective repair data provided in its cable risk model. We summarise the changes to its methodology and revised estimate of MTTR below.

59. Of the 1,136 fault events classified as corrective repair (M2) in Ausgrid's cable risk model only 361 (32%) have known causes of failure as shown in the table below.

Table 2: *Summary of known and unknown fault causes*

Fault cause	No. of records
Failure/defect records with known cause	361
Root cause unknown	
Cable (General) Low Oil pressure various leaks	526
Cable serving low IR to earth	249
Total	1,136

Source: Ausgrid cable risk model

60. The number of events where the cause is not known represents 68% of the available records. Keeping good records is a key aspect of looking after pressure cables (both Oil and Gas). Industry references such as the UK Energy Network's Association

---

[17] Ausgrid response to AER information request 25 – Supply to inner Sydney and CBD v1.1, page 2

[18] TransGrid - information request #048 – PSF cable reliability and demand forecasts – 02/05/2018

[19] TransGrid IR042 Ausgrid Item 4 Frequency Weighted M2 MTTR Explanation 20171219, page 1

[20] Ibid

publication *Code of Practice for Maintenance of Self Contained Oil Filled cables* provides details of the data requirements for failure events.

61. The severity of these events are not able to be assessed from the information provided by Ausgrid, to ascertain whether they relate to small maintenance tasks (ie small levels of oil pumping that have been noted to occur but not investigated), a higher quantity of oil leakage (which is classified as a 'Low Leak"), or a more serious issue. Small oil leaks are known to occur even when cable systems are new. There can be several very minor leaks/weeps along the cable at joints or often on the pipework and gauges and are not typically an indication of asset degradation. These low levels are simply monitored and the source of the leaks may never be found (or investigated further.)

62. As noted above, notwithstanding the issues with the robustness of the fault event data in its corporate system, Ausgrid has allocated the failure records where the cause is unknown on a proportional basis across its 66 fault types in its cable risk model according to a set of business rules.

63. Whilst the approach of allocating the unknown causes in some proportion may be reasonable, Ausgrid's method assumes that the unknown causes follow the same 'profile' of volume as the known ones. If, as noted, the oil leak faults are minor in nature, then there is less likelihood they will reflect the causes to which the allocation business rules apply.

64. Based on our experience with pressure cables, the behaviour and failure profile for each cable is unique – two circuits side by side can have very different leakage rates and even causes of leaks / failure. Specialised staff, such as oil mechanics, become familiar with different cables and what to expect over the years as they work on them. This is typical of many engineering systems and presents a challenge for maintaining this corporate knowledge.

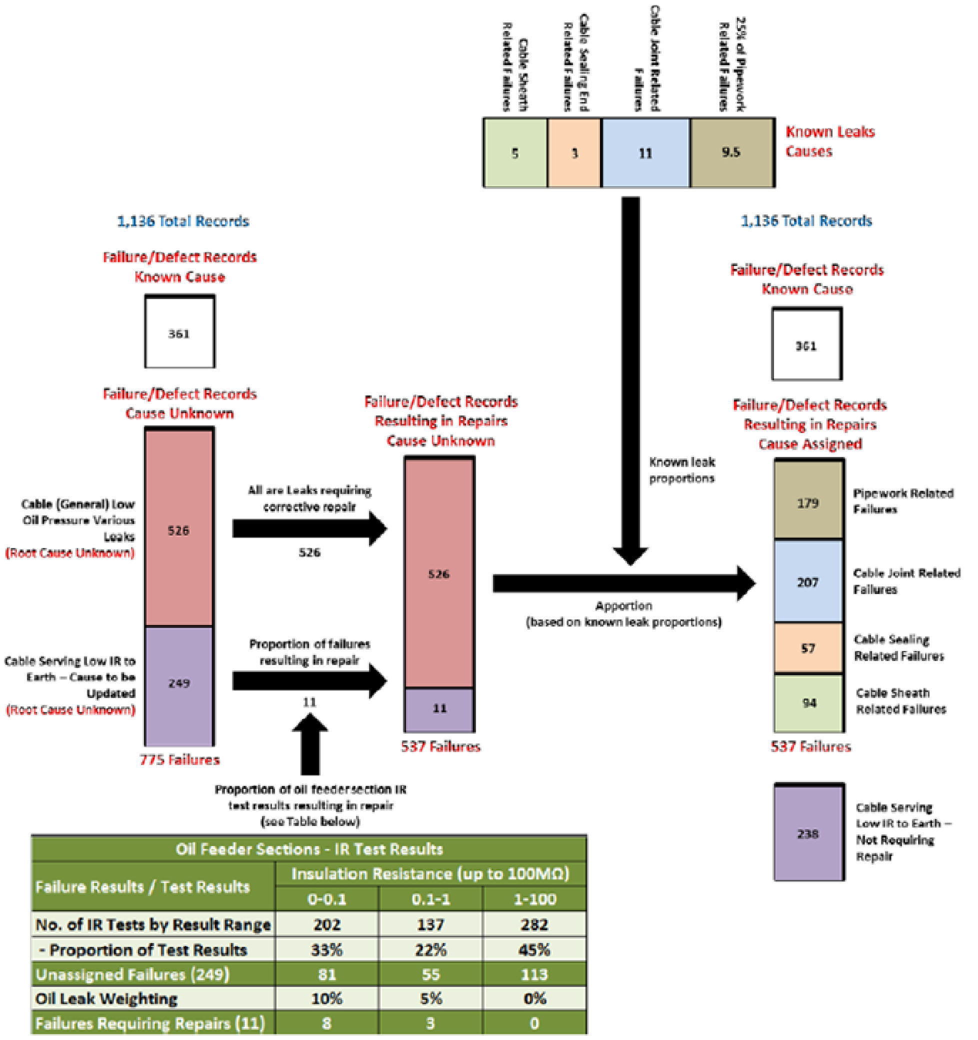
Allocation methodology

65. Ausgrid has applied a series of business rules to allocate the 775 fault records with an unknown fault cause on a proportional basis to a subset of the 66 fault types,[21] as shown in the figure below.

---

[21] TransGrid IR042 Ausgrid Item 4 Frequency Weighted M2 MTTR Explanation 20171219

Figure 1: Ausgrid's Methodology Applied to Failure/Defect Records with Unknown Cause



Oil Feeder Sections - IR Test Results			
Failure Results / Test Results	Insulation Resistance (up to 100MΩ)		
	0-0.1	0.1-1	1-100
No. of IR Tests by Result Range	202	137	282
- Proportion of Test Results	33%	22%	45%
Unassigned Failures (249)	81	55	113
Oil Leak Weighting	10%	5%	0%
Failures Requiring Repairs (11)	8	3	0

Source: Figure 1, TransGrid IR042 Ausgrid Item 4 Frequency Weighted M2 MTTR Explanation 20171219

66. As shown in the figure above, Ausgrid has determined that only 11 of the 249 low IR readings are likely to result in faults, and when added to the 526 oil pressure faults, a total of 537 failure events have been allocated to 4 failure event groups associated with oil leaks.[22] The allocation is based on the proportion of fault events that have already been assigned in its corporate system, noting that for pipework faults only 25% are deemed to result in faults.[23]

Ausgrid's cable risk model

67. We reviewed the composition of the raw data provided for corrective failures, and the results are shown in the table below. To simplify the presentation, we have aggregated the failure events where the total number of fault events for that fault event type comprised less than 10 events. This is presented as a new failure event named 'other categories' in the table below.

---

[22] Oil leaks associated with pipework, cable joints, cable sheath and cable sealing ends

[23] TransGrid-IR042-Ausgrid-Item 4_Frequency Weighted M2 MTTR Explanation-20171219-PUBLIC

Table 3: *Distribution of raw corrective repair fault events by fault event type*

Failure event	2009	2010	2011	2012	2013	2014	2015	Total
Fault events with unknown cause	**251**	**10**	**20**	**262**	**92**	**32**	**112**	**779**
low oil pressure	251	10	20	12	92	30	111	526
low insulation resistance to earth				250		2	1	253
Fault events with known cause	**35**	**39**	**41**	**100**	**52**	**37**	**53**	**357**
false activation	6	14	21	17	16	6	13	93
other categories (indiv. < 10 events)	5	2	6	9	9	8	13	52
high gas content	1			39	10	1		51
leaks	5	6	1	10	8	15	2	47
shorted	4	2	9	20	3		7	45
fails to complete circuit	12	7		2	5	2	9	37
No alarm	2		4	3	1		7	17
calibration drift		8				5	2	15
Total	**286**	**49**	**61**	**362**	**144**	**69**	**165**	**1,136**

Source: EMCa analysis of Ausgrid's cable risk model

68. In its oil filled cable failure tree analysis, Ausgrid has identified that 4 of the 253 failure events assigned to low insulation resistance to earth were caused by chemical attack and removed these from the list of unknown causes. This reduces the number of unknown causes to a total of 775, which aligns with other Ausgrid documentation and which we have relied on in our analysis.

69. From the table above, we observe that approximately 70% of the failure event data is categorised to two failure events: (i) low oil pressure and (ii) low insulation resistance to earth. These are also the two failure events that Ausgrid has identified as not having a clear fault cause.

70. On closer observation of the data, these two failure events are heavily influenced by data recorded in a single year.

    - For low oil pressure, Ausgrid recorded 251 failure events in 2009 which is materially higher than any other year in its analysis. When removed, the average reduces from 75 per annum to 46 per annum.
    - Similarly, for low insulation resistance to earth, Ausgrid has recorded 250 events in 2012 which is a clear outlier when reviewed against the available history of events.

71. Ausgrid has not explained the composition of these two data points. We note that the data is sourced from "*1A_ Subtrans Oil Cable Failure Model - Post Validation v1_09.xlsx*" which suggests to us that Ausgrid has done some level of data validation. However, given the large number of unknown failure events and in the absence of better information, the inclusion of these two data points indicates to us that:

    - the results are more likely to be the result of targeted inspection and maintenance practices, that are not typical of the underlying operating practices of Ausgrid, and therefore not representative of the health of the cable assets; and/or
    - the data may be in error, including incorrect categorisation of the data or possible duplication of data.

72. Due to lack of differentiation provided for the events in the cable risk model, that is each event is only assigned a year of the failure event occurring, the risk of

duplication of data or erroneous data is likely to be present. We were not provided with any evidence of verification of this data to mitigate this concern.

73. For example, the first series of data in the data set is for 'cable (general), low oil pressure, various leaks' as shown in the table below. There are 10 failure events assigned to the same failure location T.T.000202/00 in the year 2009. There is insufficient information provided to discern whether this is duplication of a single event, or ten discrete and independent events.

Table 4: *Sample of oil leak failure events*

	notif type	Functional Location	Part	Failure	Cause	Failure Year
1	M2	T.F.000202/00	Cable (general)	low oil pressure	various leaks.	2009
2	M2	T.F.000202/00	Cable (general)	low oil pressure	various leaks.	2009
3	M2	T.F.000202/00	Cable (general)	low oil pressure	various leaks.	2009
4	M2	T.F.000202/00	Cable (general)	low oil pressure	various leaks.	2009
5	M2	T.F.000202/00	Cable (general)	low oil pressure	various leaks.	2009
6	M2	T.F.000202/00	Cable (general)	low oil pressure	various leaks.	2009
7	M2	T.F.000202/00	Cable (general)	low oil pressure	various leaks.	2009
8	M2	T.F.000202/00	Cable (general)	low oil pressure	various leaks.	2009
9	M2	T.F.000202/00	Cable (general)	low oil pressure	various leaks.	2009
10	M2	T.F.000202/00	Cable (general)	low oil pressure	various leaks.	2009

Source: Ausgrid cable risk model

74. Whilst we have provided a single example of a low oil pressure failure event from Ausgrid's cable risk model in the table above, we have observed multiple instances in the dataset. Similarly, there are a number of cables with multiple instances of low resistance to earth in the same year that make up the 250 data points in 2012.

75. We consider that in the absence of better information, inclusion of this data into the calculation of a frequency weighted MTTR, when allocated to events with a non-zero repair time, is likely to overstate the MTTR.

Review of modelling assumptions

76. Given our concerns with the robustness of the data, we tested the analysis by making adjustments to the business rules applied by Ausgrid to determine the variation of the MTTR using its frequency weighted calculation method.

Method 1

77. We removed the effect of the events with an unknown cause by assigning a zero repair time to all of the 775 failure event records. The calculation of the frequency weighted MTTR for corrective repair reduced from Ausgrid's proposed 1.86 weeks (or 13 days) to approximately 1 day. We note that this value is of a similar magnitude to the MTTR used in the AER's Draft Decision of 0.078 weeks.[24]

78. We consider that this value has limited value, as it is more likely than not, that some proportion of the events as recorded by Ausgrid albeit with unknown cause are failures that occurred and that a proportion of these failure events will likely have incurred an outage. We therefore focussed on identifying the proportion of these events that were likely to incur an outage by considering further adjustment methods.

---

[24] However, this analysis was based on different assumptions and a smaller dataset of 939

79. Retaining these 775 additional records with a zero repair time in the calculation of frequency weighted MTTR is likely to lead to a lower MTTR value than Ausgrid derived. The subsequent adjustment methods focussed on considering (i) removal of these records entirely from the analysis (Method 2), or (ii) modification of the apportionment of failure events to existing fault causes to that proposed by Ausgrid (Method 3).

Method 2

80. By adjusting the number of failure events to those where the cause was known – i.e. removing the 775 events associated an unknown cause – the total number of fault events reduces from 1,136 to 361. We calculate the weighted corrective repair MTTR from this data to be approximately 2 days.

81. Reducing the number of failure events associated with low oil pressure or low insulation resistance individually (and not together) – i.e. removing 526 records, from 1,136 to 610, or removing 249 records, from 1,136 to 887 - changed the estimate of weighted frequency MTTR for corrective repair MTTR to approximately 1 day.

82. As noted above, we also consider that this value understates the number of failure events that Ausgrid has likely incurred. Whilst we are concerned by the raw number of fault events that have been assigned an unknown case, in our experience utilities expend considerable resources in recording and capturing inspection and observation data that is more likely than not, indicative of events occurring on the network. We also note that Ausgrid has relied on the same dataset in the determination of its predictive oil-filled cable model, which it considers is consistent with its operational experience.

Method 3

83. We applied a series of corrections to the 775 failure events assigned with an unknown cause that were relied upon by Ausgrid to proportion to the remaining categories, to account for bias. We consider that Ausgrid has identified the relevant oil leak related fault causes to be used in its proportional allocation method. Accordingly, we did not modify the factors proposed by Ausgrid that allocated the unknown fault causes to known fault causes (based on its historical information), as we did not have sufficient information in which to propose alternate proportional factors. Our data correction scenarios are summarised in the table below.

Table 1: *Summary of fault data corrections for those listed with 'unknown cause'*

Scenario	Low insulation resistance	Low oil pressure	Total unknown fault events included
Ausgrid base case (included for reference purposes only)	*249 total: 238 with zero repair time, 11 apportioned*	*526 apportioned*	*775*
1	249 total: 238 with zero repair time, 11 apportioned	275 total: 275 apportioned	524
2	Zero records	526 total: 251 with zero repair time, 275 apportioned	526
3	249 total: 238 with zero repair time, 11 apportioned	526 total: 205 with zero repair time, 321 apportioned	775
4	Zero records	321 total: 321 apportioned	321

Source: EMCa assessment

84. The data corrections summarised in the table above, comprise the following steps:

- *Scenario 1:* Retained the 249 low insulation resistance fault events as recorded by Ausgrid, removed all 251 records of low oil pressure events that occurred in 2009 from the dataset (that appears to be an outlier), thereby reducing the total number of events from 1,136 to 885 and apportion the remainder consistent with Ausgrid's method. Under this scenario, 286[25] of 524 fault events included with unknown causes, are apportioned.
- *Scenario 2:* Removed 249 of the low insulation resistance fault events thereby reducing the total number of fault events with unknown cause from 775 to 526, assigned all 251 records of low oil pressure that occurred in 2009 a zero repair time (reducing the contribution to other fault types by 251) and apportion the remainder consistent with Ausgrid's method. Under this scenario, 275 of 526 fault events included with unknown causes, are apportioned
- *Scenario 3:* Retained the 249 low insulation resistance fault events as recorded by Ausgrid, assigned 46[26] of the 251 records of low oil pressure that occurred in 2009 to be included in the apportionment of the fault events with unknown cause consistent with Ausgrid's method, and assigned a zero repair time for the remaining 205. Under this scenario, 332[27] of 775 fault events with unknown causes, are apportioned
- *Scenario 4:* Removed 249 of the low insulation resistance fault events, removed 205 of the 251 fault event records of low oil pressure thereby reducing the total number of fault events with unknown cause from 775 to 321, and apportion the remainder consistent with Ausgrid's method. Under this scenario, 321 of 321 fault events included with unknown causes, are apportioned

85. In summary, the adjustments undertaken in Scenarios 1 to 3 resulted in a frequency weighted MTTR for corrective events in the order of approximately 7-9 days based

---

[25] i.e. 11 + 275

[26] 46 is the calculated average number of events for the period 2010-2015, excluding 2009

[27] i.e. 11 + 321

on Ausgrid's estimated repair time for each fault event type retained (unless forced to zero in the analysis).

86. For Scenario 4, the calculation produced a higher estimate of 12 days due to the removal of a large number of fault event records assigned a zero repair time in the other scenarios.

87. In reviewing Ausgrid's apportionment of unknown data, we remain concerned that the approach of simply allocating the "unknowns" in a similar proportion as the "knowns" assumes that (i) the faults are all unique events, and (ii) the faults are of the same order for all of the data. Whereas for oil leaks, many of the "unknowns" may simply be small amounts of oil pumped to restore a minor leak which is more likely to be in the accessories than the main joints and may not even be particularly visible on site. Serving faults do not affect the operation of the cable in the short term and whilst some may be the result of physical contact at some time in the past, they can also be caused by soil conditions causing the protective layer to deteriorate. This is not a quick process to develop into a fault, and so it is not an issue to leave such repairs until an outage is organised for other reasons. Accordingly, it is reasonable that many of the unknowns would continue to be attributed a zero repair time, as is the case with scenarios 1, 2 and 3.

3.3 Summary

88. We have assessed the methodology and the input parameters used by Ausgrid to determine a frequency weighted MTTR value for corrective repair events (M2). We note that Ausgrid has not adjusted its methodology for deriving its MTTR value for M3 and M5 events.

89. We have not considered how TransGrid has applied its modified M2 MTTR value in in its own analysis of cable unavailability, nor have we reviewed any information pertaining to TransGrid's analysis or modelling of the timing of its PSF project.

90. We find that adopting a frequency weighted MTTR for corrective repair is reasonable. However, Ausgrid's method of apportioning events with unknown causes is likely to overstate the MTTR.

91. Based on application of a number of corrections to the frequency of event data, but with Ausgrid repair time estimates (which we review in section 4), results in a frequency weighted MTTR of approximately 1 to 1.5 weeks.

92. By removing the most unlikely scenario (scenario 4) a reasonable estimate of the MTTR, based on interpretation of the data provided is 1 to 1.3 weeks. Whilst scenario 4 is not a likely scenario, it is included to show the range of possible outcomes and provides an understanding of the effect of an unlikely (but not impossible) option.

4 Assessment of circuit outage times used in cable MTTR assumptions

4.1 Introduction

93. In this section, we describe the factors that we consider influence the circuit outage time for 132kV 3core Self Contained Oil Filled (SCOF) cable repairs, and our assessment of a reasonable estimate of repair time.

94. Our assessment provides information on the times taken to cover the physical repair, engineering and logistic matters relating to various fault issues occurring on 132kV 3 Core SCOF cables. The time taken to gain any third-party permits, such as for excavation in a roadway are specifically excluded as they will vary with the location and works required.

4.2 Ausgrid's estimates of outage time

95. As discussed in section 3, Ausgrid has estimated the cable repair times based on its own operational experience. The distribution of repair times are shown in the table below.

Table 2: *Distribution of M2 repair times in Ausgrid's cable risk model (weeks)*

Repair times (weeks)	No. of failure events
0	48
1	5
2	1
3	1
4	8
8	2
12	1
Total	66

Source: Ausgrid cable risk model

96. The largest repair times are associated with failure of a cable joint as identified in the table below.

Table 3: *Longest M2 repair times in Ausgrid's cable risk model*

Part	Failure	Cause	Repair time (weeks)
Cable joint	leaks	cable electrical failure.	12
Cable joint	leaks	fatigued / cracked barrier (stop joint).	8
Cable joint	box (coffin) leaks	cracked bitumen.	8

Source: Ausgrid cable risk model

4.3 Our assessment

4.3.1 Estimated repair time for cable failure

97. We have estimated the repair time for a cable failure to provide a reference for the completion of other repairs to the cable system.

98. The total repair time is the combination of individual times for the execution of the steps necessary for repair/recommissioning of the fault. The steps identified are sequential in nature such that their sum of the individual circuit outage times is the total time taken to restore the circuit to re-energising and thus is the repair time.

99. The repair steps are as follows:

- Establish the location of the fault.
- Excavation to confirm the location.
- Excavation to suit the chosen repair method – this is normally cutting out a section of cable (often a failed joint) and replacing it with a short new section of cable with two new joints to the existing cable.
- Laying in the new section of cable.
- Preparation of the cable for cutting/repair.

- The jointing of the sections of cables.
- Re-establish the oil pressure system.
- Testing of the circuit.
- Restoration of the circuit to service.

100. When establishing the cable outage times, three classifications can be defined as shown in the table below.

Table 4: *Summary of Cable and Joint Failure repair times*

Classification	Elaboration	Estimated circuit outage times
Emergency Conditions	Faults are often given priority over all other matters, staff plant and equipment are immediately redirected from other tasks, full 24hr shift-work is adopted wherever it will shorten the repair time. (e.g. making a joint will be by two teams working 12hrs shifts)	Restoration of the circuit to operation in 6 to 7 days[28].
Normal Conditions	Faults are undertaken as part of routine works and prioritised against other matters. Accordingly, there may be delays for staff, plant or equipment completing an existing task. Normal hours would be worked (e.g. one team working 10hr days on a joint)	Restoration of the circuit would be in the order of 13 to 17 days, (i.e. this is where there are no delays caused by the network operator)[29].
Normal Conditions (extended) – considering possible technical delays	As for normal conditions plus an allowance for staff plant or equipment issues (e.g. key staff sickness, an item failing in the oil truck). Note delays by third parties, such as obtaining permits or approvals is excluded.	It is difficult to predict this situation. Possible significant delays include: - • Difficulty locating the fault • Access issues for excavation (excluding any permits) • Lack of spares, oil trucks, staff • Oil flushing issues/oil quality • Pre-commissioning identifies other incipient faults These delays could double the time estimated for normal conditions.

Source: EMCa analysis based on expert opinion

101. We explore the factors that influence each of the cable repair steps in Appendix B. We consider that completion of a repair under emergency conditions is more likely than not to represent 'ideal' conditions that are associated with a shorter repair time when compared with normal conditions. This is not always the case, and whilst we have provided an assessment of emergency conditions, we suggest reference to normal conditions is used for any comparisons with TransGrid.

---

[28] This assumes a) that if two joints are needed two sets of jointing teams are available, b) 24 hr working is adopted wherever possible

[29] Ibid

102. The following table summarises the typical times we would expect for a cable and joint failure. The individual factors are discussed in greater detail in Appendix B. A case study is also provided in Appendix C.

Table 5: *Summary of Cable and Joint Failure repair times (days)*

Repair step	Emergency conditions	Normal conditions	Normal conditions (extended)
1. Testing to locate the fault	<1	1	2
2. Excavation for location	<1	1	2
3. Excavation for repair	1	2-3	3-4
4. Laying of cable section	included	included	included
5. Preparation of cable	1-2	2-3	3-4
6. Jointing	2	5	10
7. Re-establish oil pressure	1-2	1-2	3-5
8. Testing of repair	<1	<1	1-2
9. Re-energise circuit	<1	1	1
Total	6-7 days	13-17 days	25-30 days

Source: EMCa assessment

103. We have assumed that major cable or cable joint failures are categorised as breakdown repairs (M3), and a repair time has been assigned. Our assessment of repair time[30] is much lower than proposed by Ausgrid.

104. For corrective repair (M2) we consider that a repair time of zero is reasonable, as Ausgrid has applied.

4.3.2 Estimated outage times for cable system repairs

105. The repair of failed cable system components, including detected oil leaks follows a similar process or repair steps as described above. However, there are differences which impact on the time taken for restoration of the circuit that when summed result in lower estimate of outage and repair time.

106. The repair times associated with failed cable system components is often longer than the time required for an outage, as in some cases the repair can be undertaken without an outage or included as part of other works completed within a planned outage.

107. We explore the factors that influence each of the cable repair steps in Appendix B. We provide a summary of the outage times for typical failure types in the table below, where Ausgrid has nominated that an outage is required.

---

[30] Excluding third party approvals and associated restrictions etc

Table 6: *Summary of Ausgrid and EMCa outage time assumptions*

Part	Failure	Cause	Ausgrid M2 Unplanned MTTR (weeks)	EMCa assessment M2 outage times (weeks)
Cable (General)	low oil pressure	various leaks.	0	0
Cable joint	box (coffin) leaks	cracked bitumen.	8	1
Cable joint	Cracked lead wipe	fatigue (ground movement / vibration).	4	1
Cable joint	Cracked lead wipe	incorrect backfilling.	4	1
Cable joint	Cracked lead wipe	poor technique - initial construction.	4	1
Cable joint	leaks	cable electrical failure.	12	2-4
Cable joint	leaks	defective oil line insulator.	2	1-2
Cable joint	leaks	fatigued / cracked barrier (stop joint).	8	2-4
Cable joint	leaks	loose/missing blanking nut.	1	1
Cable sealing end	Cracked lead wipe	cable movement.	1	1
Cable sealing end	leaks	cable electrical failure.	0	0
Cable sealing end	leaks	cracked cement - porcelain/baseplate.	3	1
Cable sealing end	leaks	defective oil line insulator.	1	1
Cable sealing end	leaks	loose/missing blanking nut.	1	1
Cable sealing end	leaks	defective wipe.	1	1
Cable Sheath	Leaks	damage by electrolysis/corrosion.	4	1-2
Cable Sheath	Leaks	damage by termites/insects.	4	1-2
Cable Sheath	Leaks	damage by tree roots.	4	1-2
Cable Sheath	Leaks	Damage from excavations etc.	4	1-2
Cable Sheath	Leaks	Serving Deterioration	4	1-2

Source: EMCa assessment

108. As shown in the table above, our estimates[31] of the outage time for corrective repair (M2) events are generally lower than the values estimated by Ausgrid. We expect that the extent of repairs assumed for each fault time will influence the repair time. We also expect that the inclusion of planning and management of the repair site, associated approvals and permits, and local management issues will also contribute to increased repair times.

109. Accordingly, we would expect that the outage times for breakdown repairs (M3) to be longer than for corrective repairs (M2).

4.4 Summary

110. We have observed a wide range of estimated outage times associated with the different types of faults, damage and failure modes of oil filled cables assumed by Ausgrid.

111. We have undertaken an experienced based review of the likely outage times and developed alternate estimates of time required for failure events against the relevant M2 failure events identified in Ausgrid's Cable Failure Mode tree.

112. In our assessment, we have excluded the time (and associated delay) associated with planning, approvals, permits or similar required of third parties and the associated working practice restrictions that may be imposed, and will likely reduce efficiency and extend the required repair time and outage times. These may include restrictions such as working at night, traffic management and temporary restoration of excavations during the day.

---

[31] Excluding third party approvals

113. Ideally a network operator will pre-plan with relevant authorities for the possible works required if a cable fault occurs so that delays are minimised, particularly under emergency and/or breakdown conditions. Under emergency conditions, the importance of supply safety and restoring electricity supplies would need to be clearly conveyed to relevant third parties.

114. From an engineering perspective, whilst jointing times can be reasonably accurately predicted, many steps in the repair process are subject to uncontrollable issues to ensure that the oil system is properly managed and its integrity is maintained/restored.

115. In more than half of the cases we reviewed, our estimate of outage times was lower than that proposed by Ausgrid.

116. When we apply the lower outage times to the frequency weighted methodology (as proposed by Ausgrid and unadjusted), we calculate a frequency weighted M2 MTTR of approximately 0.5 to 0.9 weeks.

117. This estimate excludes consideration of factors for uncertainty, engagement and planning approvals which, when applied are likely to increase the MTTR. We consider that the determination of these factors is directly related to Ausgrid's operational practices and experience of its population of oil-filled cables. We would expect that the addition of these factors would increase the estimate of MTTR by a material amount.

118. When we incorporate the lower outage times developed by our cable expert (as discussed above) to the corrections made to Ausgrid's frequency data (discussed in section 3), and apply these adjustments to the frequency weighted methodology, the calculated estimate of MTTR is approximately 0.3 to 0.4 weeks. As stated above, factors relating to uncertainty and third-party approvals are not included in this estimate. Corrective repair, whether undertaken during normal or emergency conditions is likely to have some component of uncertainty and third-party approvals required. Determination of these factors will vary between fault types and locations, and when included, increases the estimate of MTTR to a value approaching 1 week.

Appendix A – Letter of Opinion

Richard Gibbons
99b Waitangi Falls Rd
RD1, Waiuku
Auckland,2681
Ph: 09 235 3351
Cell: 027 22 88 160
E Mail: richard@lth-limited.com

LTH LIMITED

To Whom it May Concern:

I have undertaken a review of the data provided by TransGrid (and including data and assessment which originates from Ausgrid) relating to the time to repair various failures or problems on 132kV Oil Filled Cables (SCOF type cables). The review included differentiating between the physical repair time for an incident and the actual time that the circuit would be unavailable for service (MTTR).

Allowances have been made for the engineering and logistics related issues that can delay repairs, but not for delays caused by third parties such as roading authorities (e.g. Councils)

I have based my review on my past experience with general exposure to SCOF cables starting with my time as an operational engineer in London. My qualifications as a cable expert include three years as system planning engineer specifying cables and ten years as the executive responsible for the operation of the Auckland cable fleet. This included SCOF 132kV cables (operating at 110kV) and 33kV cables as well as other types of construction. The period includes the Auckland CBD cable failure outage. I have attached a copy of my qualifications to this opinion letter.

My review includes assessing the overall approach used and significant estimates made by TransGrid and Ausgrid management, as well as evaluating the overall estimate of MTTR. I believe that the review I have undertaken, and which is described in this report, provides a reasonable basis for my opinion.

In my opinion, the various detailed times identified in the report provide a reasonable basis for the associated calculations to establish an average MTTR.

Whilst the report identified specific references the wider documents considered are listed as attached.

GRGibbons

Ir G. Richard Gibbons

BSc. (Hons), Dip BA, Cert Co Dir; FIET, C.Eng (UK); FEngNZ, CPEng (NZ); Int PE;Life M.EEA; FIMNZ ; C.MInstD

Position **Principal Consultant & Director**

Qualifications

- Bachelor of Science (Honours), Electrical & Electronic Engineering, City University, London, 1972
- Post Grad. Diploma of Business and Administration, Massey University, New Zealand, 1984
- Graduate, New Zealand College of Management, (AMF1) 1987
- Certificate in Company Direction (Institute of Directors) NZ 2007
- Chartered Engineer (UK); Chartered Professional Engineer (Business, Electrical) (NZ);
- FIET, FIPENZ, FNZIM, CMInstNZ.
- International Professional Engineer
- Chartered Director
- Life Member EEA NZ (Inc).

Specialisation

- Qualified in engineering, management and governance
- Over 40 years' experience in the electricity supply industry in engineering and management
- Positions including over 20 years at Executive Management level.
- Executive Experience as an Asset Owner, Contractor and Consultant.
- Management experience in HR, stores, logistics, transport and property matters
- Experienced in dealing with Regulators
- Experienced in change management and the use of performance measures to improve customer focus and deliverables - including the use of benchmarking studies
- Management experience in other infrastructure industries (gas, water, and wastewater)
- Extensive Risk Analysis & Project Management experience
- Industry representative on Governmental committees
- Appreciation of and experience in Cultural matters.

Experience (Cont)

- Management of companies including reporting, analysis, client relationships, development/growth, recruitment, financial performance, etc.
- Expert witness for various industry disputes.
- Incident investigations
- Specialist network management/regulatory advice to Line Companies.
- Design, construction, maintenance and management of distribution systems
- Former Director Standards New Zealand
- All aspects of network design, operation & maintenance for Electricity Distribution and Transmission

Projects (Examples)

- Review of Line Company compliance to PAS 55-1
- Investigation of Companies performance during Major Gas Outage in CBD
- Review of Line Company performance during/post Cyclone event
- Fatality investigation – live line work

- Review of load control operation by line company for dispute with retailer
- Security of supply studies
- Risk assessment for networks
- Assessment of value of Lost Load for line companies
- Co-author EEA Guidelines for the Security of Supply for New Zealand Networks
- Due diligence studies on networks and contracting organisations
- Review of Network Companies Expenditure Plans for Regulators
- Analysis of Network Improvement Opportunities against costs.
- ODV related matters
- Risk Analysis from Board, management and Operational levels
- Re-organisation/restructuring for corporatisation

G. R Gibbons – Cables Supplement to CV

My cables experience covers work in various roles including planning, design, construction and operation, over some 40 + years.

Specific projects of interest are: -

System Planning Engineer (Auckland)

Auckland CBD Future Proofing – the CBD Tunnel Project - I developed the original concept for installation of 2 X 110kV circuits some 12km long. Compared laying in the street vs tunnel option. Prepared overall project proposal including costings and presented to the Board.

Several other purchases/projects requiring cables at 110kV and 33kV - specifications, purchases, installation contracts – physically this included CBD, normal urban, rural and undersea locations. Cable types included SCOF, Gas Pressure, XLPE.

Executive Responsible for Sub-transmission System (Auckland)

Initially Manager Engineering Projects covering Planning, Operations & Maintenance, Later AGM Engineering (Chief Engineer) then GM Network covering all the network.

Auckland CBD Future Proofing – the CBD Tunnel Project. Presented the selected solution and options to Environmental Court to gain approval. As GM Network, I had overall responsibility for the project including the contracts for the construction of the tunnel and the cable contracts for supply and installation as well as board liaison.

Review of our structure and capabilities. Arranging for an overseas expert to undertake training to upskill the team and to review procedures and equipment.

Auckland CBD Outage – as GM network intimately involved with all aspects of the investigation and recovery of the situation.

As a Consultant

NZ Regulators "ODV handbook" - reviewed and developed "cost multipliers" to cover the installation of cables in different locations - urban, CBD, rural, rock, plus identifying the costs of the introduction of special traffic management (including on motorways).

Quality and technical reviewer of several 132kV cable projects (carried out by others) for Queensland and Uzbekistan.

Documents Referenced

1. "Code of Practice for Maintenance of Self Contained Oil Filled cables" issue 2 2000 UK Energy Network's Association
2. "Methods of Maintenance on High Voltage Fluid Filled Cables Including an Innovative
3. Technology Associated with Dielectric Fluid Leak Location - by Mike Engelbrecht
4. "An innovative method for finding leaks in oil filled high voltage cables" - by R H Goodwin, HV Test, Energize - May 2011
5. "SP Energy Networks 2015–2023 Business Plan Updated March 2014 Annex 132kV Cable Strategy" - SP Energy Networks
6. "Practical HV Cable Jointing and Terminations for Engineers and Technicians" IDC Technologies – 2006
7. "Power System Safety Rules Revision 5.3" - TransGrid – 2016
8. "Safe Work Practices on High Voltage Cables" - TransGrid – 2015
9. Oil Filled Cable Installations – Pirelli-General – 1939 Edition
10. Oil Filled Cable Installations – Pirelli-General – 1950 Edition
11. Auckland CBD Power Supply Failure 1998 – Ministerial Inquiry Report
12. Private papers and notes relating to the Auckland CBD Outage.

Appendix B – Factors that influence cable repair times

Introduction

119. In this Appendix we consider the factors that are likely to influence the cable repair times for (i) Cable and Joint Failure, (ii) Cable Sealing Ends, and (iii) Oil leaks. This summary has been prepared based on the experience and advice of our cable expert.

Cable and Joint Failure

120. In the following sections, we consider the factors that influence repair time for each of the cable repair steps as discussed in section 4, with specific focus on repair times for emergency and normal conditions.

Testing for Fault Location

121. Several factors impact on the time required for testing for fault location. The quickest time to locate a failure, is when the location of the failure is clearly visible and immediately reported to the network operator. More typically, it is necessary to arrange for specialist test equipment (often in a purpose-built vehicle) to travel to one end of the cable to allow the equipment to be connected to the cable and testing conducted to identify the location of the fault, after the appropriate safety isolation procedures have taken place.

122. If there are circuit breakers located at either end of the cable, then it is a straightforward process to fully isolate the faulted cable for fault location. For a Feeder/Transformer design, immediate access is only available at the source circuit breaker, so it is necessary to isolate the cable for testing at the transformer cable boxes – again this needs to follow appropriate safety isolation procedures.

123. Factors that impact on the repair time include availability of test equipment, qualified technicians and travel distance. However, the type of fault can significantly impact the fault location process. Whist less likely to occur at higher voltages, some faults can "self-heal" such that they withstand the test voltage and delay the process of

fault location as "conditioning" of the fault is needed to provide a reasonably accurate fault location. The application of multiple test methods for fault location can help reduce the time required for fault location.

124. A typical time to find a fault, allowing for getting staff and equipment to site, safety procedures and full cable isolation would be less than 1 day, approximately 12 hrs. The factors impacting on this step are largely under the network operator's control – sufficient staff and equipment.

Excavation to confirm location

125. The single biggest impact on the repair time associated with this step is the location of the fault. If the location is on a quiet street in the grassed verge, with no obstructions, ready access to staff and equipment, and no traffic management requirements, then the excavation could be accomplished in approximately four hours. This is based on initial removal by machine then hand digging to locate the cable – or joint.

126. Conversely, if the location is in the middle of a main highway then setting up traffic management requirements can take several times the digging time to achieve. In the CBD area, further restrictions may be put in place limiting excavation to certain hours overnight – with a requirement to temporarily re-instate the excavation for the next day (e.g. by using steel plates).

127. Other factors that may impact the repair time include incorrect records – the cable measurements from a reference point being incorrect, or the reference point no longer existing due to changes in the local conditions (although this is less likely for major circuits). Mobilisation of staff and machines should take place whilst fault location is underway so that the excavation process is able to start immediately[32].

128. The shortest time to confirm the location of a fault, allowing for mobilising staff and equipment to site, and no major access issues is approximately 8 hours, and may be expected to increase up to 1 day. The factors impacting on this step are partially under the network operator's control – sufficient staff and equipment.

Excavation to allow for repair

129. Occasionally it may be possible to achieve a repair by using a single joint at the fault location if the damage is minor, however it is nearly always necessary to affect a repair by cutting out the damaged section of cable (often a failed joint), replacing this with a spare section of cable and installing two joints to reinstate the circuit.

130. The same issues relating to the excavation for fault location apply to this repair step, however a larger excavation is required, with provision for proper access, trench safety shoring and site preparation.

131. For an easy access location, working continuously, this step can be achieved in approximately 24 hours, and increase up to 2-3 days. As noted above, the factors impacting on this step are partially under the network operator's control – sufficient staff and equipment.

---

[32] Note – appropriate resources to handle leaking oil are also required to minimise environmental damage.

Laying in the new section of cable

132. The time required for this repair step is effectively covered in the excavation item noted above, however it is identified separately to cover the various possible delays.

133. Firstly, a section of cable in good condition is required – this means that spare sections need to be secured from spares stock as availability from a manufacturer is extremely unlikely. Normally a spare length of cable will have been purchased at the time the cable was first installed which then requires storage under appropriate conditions (i.e. pressurised with oil) on drums that are able to be transported. (i.e. the timber has not rotted away). Good stock control is also necessary to ensure the "spare" cable is in fact the correct one for the circuit being repaired.

134. Provided there is no specific delay, the time to roll out and lay the cable in the trench is included in the allowances above for excavation.

135. If there is no suitable spare Oil Filled Cable then the circuit may be repaired using transition joints to XLPE cable for the new cable section. This then introduces a further complication as it will be necessary to re-engineer the oil sections of the existing cable to ensure they will function correctly, this can involve installing new oil tanks and connections which will substantially extend the repair time, and subsequent circuit restoration time. This may contribute to a technical delay that extends the repair time to several weeks to restore the cable to service. These factors are primarily under the network operator's control.

Preparation of the cable for cutting/repair

136. Before an oil filled cable can be cut it is firstly necessary to stop the flow of oil which can be under considerable pressure, depending on the level profile of the route. The normal process involves installing a special "collar" around the outside of the cable to allow liquid nitrogen to flow around the cable and freeze the oil in the cable, thus blocking the flow. Oil samples are taken at this stage to check the oil quality.

137. It will be necessary to have the specialist "oil truck" on site with the requisite equipment and appropriately qualified oil technicians to complete the required works and testing.

138. This step would typically take less than 1 day, approximately 12 hours. However, if the oil condition is found to be poor then an additional step of "flushing out" the existing oil in that section of cable will be necessary, effectively replacing it with new oil. This can add a further delay up to 2 days for long sections of cable.

The jointing of the sections of cables

139. Cable jointing is a well-established and documented process. Key issues include ensuring the site is clean and dry and all components ready for installation. Poor weather can interfere with maintaining suitable conditions for jointing to proceed, as ideal conditions should approach an indoor factory environment.

140. In addition to holding appropriate spare joints, it is often necessary to arrange for "standard" components to be machined to accommodate the actual cable repair (e.g. drilled to suit) requiring immediate access to the appropriate facilities to avoid delay to the jointing process.

141. In emergency conditions, installation of a single joint would involve two jointing teams with one following the other, each working a 12-hour shift. This should see a joint fully completed in approximately 2 days. Thus, with four teams available the two joints can be completed in parallel in the 2-day period.

142. Under normal conditions, completion of the two joints with two teams allowing for fatigue management, would require a repair time of approximately 5 days.[33] If only one team is available, working 10 hours shifts, the repair time would increase to approximately 10 days to complete the two joints. Having sufficient staff and spare joints are primarily under the network operators control, however the risk of bad weather is not controllable.

Re-establish the oil pressure system

143. With the jointing completed, the next repair step is to completely flush the affected section of the oil system to replace any contaminated oil with pure product. As noted above the time for this will vary depending on the height profile of the route.

144. In addition, a major part of this step is to test the oil quality as it flows out of the far end. This takes place during the pumping/flushing process and the test results are used to determine when to finish the flushing process, making the cable ready for testing.

145. Typical times for this step would be approximately 1 to 2 days. It is a continuous process so sufficient staff must be available to work on shifts irrespective of whether it is under emergency or normal conditions. Having sufficient staff and oil equipment are primarily under the network operator's control, however the flushing/testing process reflects several cable factors which are outside their control.

Testing of the circuit

146. The penultimate step in restoration of the cable circuit is to check that the cable is in a suitable condition to be re-energised. This is carried out by applying an HVDC overvoltage to the cable to ensure there are no other actual (or immediately incipient) fault sites.

147. The test equipment should be on site ready to carry out the tests as soon as the jointers have given clearance that they have finished work and the oil technicians have completed the post jointing flushing and testing. Following normal operation procedures, the temporary earths will need to be removed before the tests take place as part of the switching processes.

148. As noted above if the circuits are "Feeder-Transformers" then further work will be necessary to re-earth the circuit to allow the links at the transformer end to be replaced after a successful test, increasing the repair time.

149. Under emergency conditions the process should take less than 1 day, approximately 8 hours provided the readings are acceptable, and increasing to approximately 12 hours for normal conditions. The key factors for this step are having sufficient staff and equipment available. Both are under the network operator's control.

---

[33] Note that the liquid nitrogen freezing process will be discontinued once the jointing process has progressed sufficiently to restrict the flow of oil.

Restoration of the circuit to service

150. Once the testing has cleared the circuit for restoration (and if appropriate the transformer end links replaced) then the circuit can be restored. Allowing for normal safety operating procedures this should only take an hour or so. Delays can occur if the switching is under the control of a third party (e.g. the grid operator) who may have different priorities, requiring close liaison in the closing stages of the repair to ensure there are no delays.

151. Common practice is to energise the repaired cable from one end, but not to load it, typically for a 24-hour period. (Called "on soak") this is to ensure the circuit is fully ready for restoration. This has been included in the estimate of repair under normal conditions.

Planning and site management factors

152. As noted in several sections above there are various factors that impact on the circuit restoration time which require careful planning coordination, and predominantly impact on site management type issues. These can be split into categories as follows: -

- Under the network owner's control – availability of staff, (including contractors) spares, equipment (owned or hired), accuracy of cable records.

  Whilst the network operator will have taken reasonable steps to manage the factors under their control to industry standards, some events that may impact the repair time may not be able to be foreseen.

- Controlled by outside parties - road or property access – infringement of cable "corridors" by third parties (e.g. other utility owners), surface level changes (e.g. from road reconstruction) - substation access for testing/repair by other utility owners

  The first (and usually major) delay factor comes from restrictions on how and when excavations can take place, usually imposed by the road management authority, but if the cable is not in the road reserve other land owners can equally impose restrictions. In very busy areas these restrictions can limit the available excavation time to within 8 hour windows, or similar. When considered along with the requirements to mobilise and de-mobilise plant and vehicles, the repair times may be further extended.

  A secondary issue is that of the impact by third parties on the cable "corridor". Whilst regular cable route patrols should pick up major changes (such as a significant road surface level change) there is the strong possibility for other utilities (water, gas, telecom, etc) to put cables or pipes above or close to the sub-transmission cable which do not become apparent until it is excavated, say for a cable "freeze" operation. The impact of these will vary, for example if the road level has been increased then the extra depth of digging may require a higher grade of trench shoring (collapse protection) requiring time to install before anyone can enter the trench. This can often take one or two days to organise and effect, especially if the site access is difficult. For other utilities it may be necessary to have them re-routed to clear the required worksite again adding delays to the cable circuit restoration time, typically a day or so for most events.

- Uncontrolled – weather, fault characteristics, reaction of neighbours to works

Uncontrolled issues are the hardest to predict. The common one is that of bad weather. Whilst heavy rain may simply delay suitable jointing conditions for a day storms can result in trench collapse and (if good precautions are not taken during work) even to water entering the cable. Whilst a delay of a day or two would be typical this can rapidly increase under a "worst case" series of events and several days could be lost from an extended storm with flooding.

Neighbours' reaction to works should be able to be handled with good PR, including compensation or other similar actions if necessary. Special care may be needed with registered historic buildings and similar which restrict excavation methods to avoid vibration. Whilst rare, there can be significant delays caused if an impacted party seeks an injunction to stop work.

153. The above list is not necessarily complete but is provided to show the typical items that can impact on repair works and increase the time taken from the repair times nominated under normal conditions.

Cable Sealing Ends

154. The failure of a cable sealing end effectively follows a similar process to the repair of a fault elsewhere on the cable circuit, however there are differences which impact on the time taken for restoration of the circuit.

155. The typical arrangement for connecting a cable to overhead equipment is using a three-core cable to enter a trifurcating joint and be split into three single cables ("tails") which are then terminated in individual oil filled sealing ends. Current practice when an item in this arrangement fails, is to replace the trifurcating joint with one that connects the three-core oil filled cable to three single core XLPE cables and use XLPE sealing ends.

156. When compared with the repair time for a cable or joint failure, some aspects are easier and overall will require a reduced repair time. The failure location is usually obvious and thus it is not typically necessary to perform testing to locate the fault. Access is within a substation and thus whilst safety process must be followed there should be no delays for the limited excavation necessary.

157. The work on the oil cable still requires freezing to contain the oil flow until the new joint is in progress and post completion flushing is still necessary. However, the actual trifurcating joint usually is more complex than a straight-through joint and there is additional work to remove all of the existing cables and sealing ends and then (if necessary) modify the stands for the sealing ends. The sealing ends themselves have to be completed.

158. Typical repair times under normal conditions are approximately 5 – 7 days.

Oil leaks

Overview

159. Traditionally the process of locating oil leaks uses the freezing process noted above (Cryogenic Process) to sectionalise the cable and thus to locate the faulty cable section. This involves reviewing the pressure drop gradient across a cable section, or if necessary gradually separating the cable into smaller sections to isolate the problem. Each "freeze" requires excavation and the specialist equipment and technicians with their associated potential for delay.

160. The cable is required to be de-energised during the freezing process which can take an extended time, particularly for longer sections of cable.

161. PFT injection and tracing[34] has since been introduced and has been widely adopted. PFT's are perfluorocarbon tracers, which were developed by Brookhaven National Laboratories and which have unique properties of being liquid at room temperature, totally non-toxic and thermally inert. The gas is permanently injected into the oil system and when leaks occur a detector van drives the route searching for leakage. The process has been shown to be accurate to within a few meters. This location process takes place with the circuit remaining energised[35] and disconnection is only required once the location has been found and repair work is undertaken and deemed to require an outage.

162. There is a risk that the PFT process could fail to locate the leak and it becomes necessary to resort to traditional methods which could result in an extended outage period.

Leaks at Joints

163. A common failure mode is for an oil leak to occur due to the lead wipes at the end of the joints cracking. This can be due to ground movement, repeated cable expansion and contraction or poor initial installation. The basic repair is to remove the original wipe and to re-do the process[36].

164. Experience has led to the joint normally being reinforced across this weak spot by the use of fibreglass tapes and resin to provide greater strength and rigidity. It is normally necessary to freeze the cable either side of the joint to stop the oil flow and thus it is necessary to flush and re-establish the oil circuit after completion.

165. Allowing for typical times for excavation, oil preparation and restoration and joint repair time a repair time of approximately 5 – 7 days is considered typical. This may be shortened a little under ideal conditions (perfect access, no excavation, etc) or equally increased by a few days due to technical delays.

Leaks due to Sheath Damage

166. Where damage occurs to a cable that results in the cable sheath being breached and oil is leaking, but there no electrical fault, the repair typically requires the damage to be repaired by cutting the cable at the damage point and installing a single joint. This could occur as a result of the sheath suffering minor damaged ("nicking") by an excavator or directional drill that did not cause an oil leak at the time, but the damage was sufficient for the material to fail later.

167. If damage is not evident from third party excavation, which is generally reported, the oil leak can be identified by the pressure drop and the detection process for leaking

---

[34] Originally trialled in 1998

[35] Subject to the leak being "sustainable" and not "unsustainable" as the latter case requires the cable to be taken out of service to avoid electrical breakdown. Refer Energy Networks Association (UK) Engineering Recommendation C84_2 Code of Practice for the Maintenance of Self-Contained Fluid-Filled Pressure Assisted Cable Systems

[36] With the established history of problems with some manufactures types of joints gradually degenerating due to cable movement within the joint – "bird-caging" – it is good practice to remove the wipes from both ends and to slide the joint sleeve along to allow a full inspection of the state of the joint. If the joint is found to have deteriorated significantly then a replacement process becomes necessary as outlined in section A)

PFT noted above will be followed. The circuit will need to be taken out of service for the repair, including initial excavation to establish a joint bay for the work.

168. As oil preparation and later re-establishment is necessary, together with (albeit reduced) excavation and its associated difficulties, the repair times effectively approach that of a full cable/joint failure as noted above, less the time to locate the fault as the circuit will remain energised whilst the PFT process takes place.

169. Under normal conditions a repair time of 7 to 8 days would be required allowing for some delays.

Serving Damage

170. Where the outer cover of the cable is damaged or has deteriorated due to environmental conditions/initial poor installation but there are no oil leaks then the issue is to restore the integrity of this cover (serving). Provided it is possible to use a method that does not require direct contact with the metallic cable sheath or armouring then this is permitted to be carried out with the cable energised[37].

171. If major excavation is required or a suitable method of repair is not available, then the circuit will need to be shut down for the period of the work. A typical repair time (including for excavation) would be 1 day.

Accessories

172. Under normal circumstances it is typically permitted to carry out repair works such as for oil leaks, following approved procedures, with the circuit remaining energised[38] and therefore not require an outage.

173. As for sheath repairs, if it is not possible to follow the required practice then it would be necessary to shut down the cable for the required time, this should only be a few hours.

---

[37] Refer Power Systems Safety Rules 7.1.3 (c)

[38] See ref 8 and also TransGrids own Guide "Safe Working Practices on High Voltage Cables"

Appendix C - Case study: 1998 Auckland CBD Crisis

Introduction

174. In this section we provide our observations on the 110kV (132kV) Oil Filled Cable repairs under emergency conditions that occurred in response to the 1998 Auckland CBD cable failures and extended black-outs.

175. As a case study the repair times and observations provided are intended to provide evidence of the factors to be considered in the repair times and outage times for repair of oil filled cables and cable systems, and the range of times that may be incurred by the network operator. The repair and outage times described here are not indicative of normal conditions and will vary with the conditions that TransGrid may be exposed to in similar circumstances.

Background

176. In February and March of 1998, the city of Auckland New Zealand experienced a five-week-long power outage as a result of the failure of four cables[39] supplying the central CBD.[40]

177. Following failure of two gas-filled cables supplying the CBD, additional load was transferred to the two oil-filled cables. The two oil-filled cables were Pirelli 3 core self-contained oil filled (SCOF) 132kV cables operating at NZ standard voltage of 110kV. The resulting failure of the oil filled cables resulted in total loss of load and subsequently rotational load cutting outages for several days and load restrictions for some weeks, affecting the Auckland CBD.

---

[39] Comprising two gas-filled cables and two oil-filled cables

[40] Inquiry into the Auckland Power Failure - Technical Report on Cable Failures Integral Energy - 5 May 1998, accessed on 22 March 2018 at https://www.nrc.gov/docs/ML1233/ML12334A663.pdf

178. The first oil-filled cable failure occurred due to thermo-mechanical stresses at the cable joint located in a main road in a section of cable with a major profile issue for the oil circuit.

179. This fault took a total of 12 days to repair it to re-commissioning stage, only to find on HVDC testing that there were other incipient faults on the cable circuit so that it did not go back into service at that time. The cable was subsequently abandoned once it was established that there were multiple joint failures in the circuit.

180. The second cable fault was due to thermal runaway in a mid-cable location. As for the first cable, it took a total of 12 days to repair it to re-commissioning stage and again it failed HVDC testing due another incipient fault. For this second cable the second fault was located (failed joint) and repaired returning to service a further 25 days later,[41] although it failed again 6 weeks later. It was also subsequently abandoned once it was established that there were multiple joint failures in this cable circuit as well as the other one.

181. Due to extent of the outages, there was extreme pressure to return the cables to service and this was reflected in the priority given to the restoration effort.

Factors influencing cable outage times

182. Considering the factors described earlier in this report, we comment on the outage times experienced as part of this event.

Fault Location

183. Locating the fault was completed in a reasonable amount of time in both cases. No special delays were identified.

Excavation

184. For the first cable the fault location was along a major road which slowed all progress. For the second the site was in a less busy street, but there was a major building site alongside the excavation. There were no delays due to other authority's requirements as the seriousness of the situation was well known, delays were simply as a result of normal traffic.

185. For both sites there were some impacts on the time to lay the replacement cable.

Cable preparation

186. There was sufficient cable freezing equipment such that it was available when needed. The first cable fault resulted in a major oil loss at it was well down a hill, this required extensive flushing to prepare the cable for work. Further the oil tests were not good (later established to be due to the deteriorated joints along the route) which increased the time to stabilise.

187. Arrangements were made to borrow an oil truck and staff from another operator to ensure sufficient resources were available.

---

[41] The slow repair time was as a result of a decision to attempt to X-Ray other suspect joints along the route.

Jointing

188. There was only one jointing team with training for 132kV joints, and this team had limited experience due to the small fleet size of cables at this voltage. Some weeks prior to the oil filled cables failure the two original CBD gas pressure cables had failed and jointers had already been engaged from overseas (Sydney County Council, SCC) as they had identical cables. (There had been an extended history of working together including placing shared orders for joints and auxiliary equipment and for training).

189. Additional jointers experienced in working on the SCOF cables were sought from Sydney and also from Queensland and flown over. As noted above an additional oil treatment truck was also obtained with staff.

190. Additional Cable joints were also obtained from SCC stock, and flown to NZ, with the manufacturer supplying further replacement spares by air in a two-week time frame.

Re-establishing the oil system

191. For the first faulted cable, the profile caused some difficulties, however the oil system was able to be effectively managed and the repair time was as expected. The second cable was also completed as expected.

Testing

192. There were no delays experienced with the testing process on either occasion in response to the primary fault. Upon subsequent testing, further faults were identified.

Summary

193. The work to repair the failed oil filled cables was carried out under emergency conditions and the overall time for each repair was approximately 12 days. This is considered reasonable as it reflects the actual issues that were encountered. It should be noted that whilst there were delays in bringing jointers from overseas, having them immediately on-hand would not necessarily have significantly reduced the total outage time as the other issues (Oil preparation, availability of joints, oil trucks, etc) would have still created delays. If all staff had been local, there were no delays with spares, oil treatment trucks, etc, then it is estimated that the repair time may have been reduced by two or three days only.