Program of Works

2017 – 2022

Transformer Bushings Replacement (PUBLIC VERSION)

Document number	N/A
Issue number	1.0
Status	Approved
Approver	Steve Owens
Date of approval	01/07/2015

ISSUE/AMENDMENT STATUS

Issue Number	Date	Description	Author	Approved by
0.3	08/04/15	Initial document	C. Odendaal P. Seneviratne	
0.4	01/07/15	Minor editing & new AusNet Services' format	C. Odendaal	
1.0	01/07/15	Initial Issue	C. Odendaal	S. Owens

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1 Summary

PROGRAM	Transformer 500 kV, 220 kV and 66 kV Bushings Capital Replacement Program 2017 – 2022
SERVICE DATE	On-going throughout period 2017 – 2022
LOCATION	Various Terminal Stations
VALUE	$ 3.4M

Table 1 – Program overview

This works program document should be read in conjunction with AMS 10-67 Power Transformers Oil Filled Reactors. It details the background and options analyses performed in order to determine optimal transformer maintenance and replacement strategies.

1.1 Program Scope

This program is to replace the following bushings from transformers at four terminal stations:

- 1 off C-I-C OIP[1] 220 kV HV Bushing;
- 9 off C-I-C 500 kV OIP HV Bushings;
- 3 off C-I-C 66 kV MV Bushings;
- 6 off C-I-C 220 kV HV Bushings;
- 3 off C-I-C OIP 220 kV HV bushings.

1.2 Program Expenditure Forecast

2017/18 ($k)	2018/19 ($k)	2019/20 ($k)	2020/21 ($k)	2021/22 ($k)	Total ($k)
680	680	680	680	680	3,400

Table 2 – Program timing and forecast expenditure

[1] Oil Impregnated Paper.

2 Program Drivers

- Network reliability, quality and security of supply:
  - The failure of bushings will result in unplanned outages of transformers;
  - The explosive failure of bushings can cause major failures of transformers resulting in extended outages (if a spare is available it can take up to 3 months to restore and if there is no spare available it can take approximately 9 months for a B transformer and 18 to 24 months for an A transformer to be restored);
  - Some of these transformers are critical transformers to the network as they are 500kV main tie transformers and are located at critical locations such as major generator connections (eg: HWTS[2]). Therefore outages of those transformers will constrain the market.

- Safety and Environment:
  - Explosive failures of bushings can result in projectiles, spill of oil and fires. All of these will present a safety risk to people working in the switchyard. Spillage of oil also poses environmental hazards.

- Financial Impacts:
  - Failure of the critical transformers will result in high market impact costs;
  - Financial penalties from incentive schemes;
  - Increased costs associated with emergency replacements following failure of bushings and major failure of transformers;
  - Costs associated with collateral damages to the adjacent plant caused as a result of projectiles and oil fires;
  - Costs associated with injuries / fatalities arisen to staff and contractors working on site as a result of projectiles and oil fires.

- Regulatory Compliance:
  - To comply with all applicable regulatory obligations or requirements associated with the provision of prescribed transmission services.

- Corporate Image:
  - To maintain the corporate image as a prudent asset manager by managing risk as low as practicable.

3 Obligations

The National Electricity Rules (clauses 6A.6.6 and 6A.6.7) require AusNet Services to forecast operating and capital expenditures to, amongst other objectives, *comply with all applicable regulatory obligations or requirements associated with the provision of prescribed transmission services;*

The Electricity Safety Act (clause 98) requires a major electricity company, such as AusNet Services to design, construct, operate, maintain and decommission its supply network to minimise so far as practicable:

a) the hazards and risks to the safety of any person arising from the supply network; and

b) the hazards and risks of damage to the property of any person arising from the supply network; and

c) the bushfire danger arising from the supply network.

In the definitions of this Act, the term ‘practicable’, means having regard to:

a) the severity of the hazard or risk in question; and

b) the state of knowledge about the hazard or risk and any ways of removing or mitigating the hazard or risk; and

c) the availability and suitability of ways to remove or mitigate the hazard or risk; and

d) the cost of removing or mitigating the hazard or risk.

This means “as low as reasonably practicable” which has been interpreted as until the safety related costs are (grossly) disproportionate to the safety related benefit.

The *Occupational Health and Safety Act 2004* (Vic) (**OHSA**) requires AusNet Services to:

> *as far as is reasonably practicable, provide and maintain for employees of the employer a working environment that is safe and without risks to health.*[3]

When determining what is (or what was, at a particular time), reasonably practicable in ensuring health and safety, the OHSA requires that regard be had to the following matters:

a) the likelihood of the hazard or risk concerned eventuating;
b) the degree of harm that would result if the hazard or risk eventuated;
c) what the person concerned knows, or ought reasonably to know, about the hazard or risk and any ways of eliminating or reducing the hazard or risk;
d) the availability and suitability of ways to eliminate or reduce the hazard or risk.[4]

[3] Section 21(1).

4 Occupational Health and Safety Act 2010, section 20(2).

4 Overview

Bushings are a relatively small proportion of the cost of a transformer, but are a very important component, providing the connection between the transformer and external equipment as well as the full insulation to earth. The failure of some types of bushings have a high probability of resulting in a transformer fire and many such failures have resulted in the complete destruction of the transformer and collateral damage to other equipment.

4.1 Risks

AusNet Services' network experienced high voltage bushing failures and fires in 1965 and 1987. In the last decade, four interstate bushing failures (2 in QLD and 2 in NSW) have included explosions and fires which ultimately destroyed the transformers involved. Bushing failures can be explosive and as a result send projectiles of porcelain in all directions, causing collateral damage to other plant in the switchyard. All of these are also a safety risk to the staff and contractors working in the switchyard. So the risks associated with bushing failures could include severe health & safety consequences to the workers as well as substantial plant damage.

4.2 Designs

There are a number of different construction / designs of high voltage bushings presently installed on the network. The population of bushings varies in age from original bushings on transformers installed 1960s & 1970s to the present installations. The bushings of the 60's & 70's are of two basic designs:

- oil impregnated paper (OIP);
- synthetic resin bonded paper (SRBP).

The C-I-C OIP and SRBP bushings are included in this program as outlined in Section 1.1. These bushings are now showing signs of advanced age deterioration that would lead to an insulation failure and possibly an explosive transformer failure. Major oil interface seals on the OIP 500 and 220 kV bushings are failing on the HWTS and KTS 500/220 kV transformers. The older 220 kV SRBP bushings on C-I-C transformers are delaminating and seal degradation is allowing moisture entry. Additionally, there have been occasions where the gauge glass on C-I-C SRBP bushings have cracked, leading to moisture entry and deterioration of the bushing. Moisture and polar contaminate ingress has been detected by an increase in dielectric dissipation factor (DDF) and capacitance. The issues with these bushings are further discussed in AMS 10-141 Asset Health Review for Power Transformers & Shunt Reactors. C-I-C have warned that these bushings would dielectrically deteriorate with time and should to be replaced before failures occur.

Neither C-I-C SRBP and OIP bushings are currently manufactured. The replacement of 220 kV SRBP bushings are therefore adapted from current 'off the shelf' bushing designs to electrically and physically fit the in-service transformers. However for 220 kV and 500 kV OIP bushings on 500 kV transformers, new bushings need to be custom designed and built especially due to the unique voltage measurement tap on the 500 kV bushings.

Over the last decade AusNet Services has raised three projects (X417, X834 and XC72) to replace deteriorated transformer bushings. Project X417 completed in early 2008, replaced 13 high risk 220 kV bushings on 5 transformers during 2004-08. Project X834 was initiated in the 2008/09 financial year to replace further 27 deteriorated SRBP bushings and was completed by 2014. Project XC72 to replace 30 high risk 220 kV bushings on 10 transformer units is in progress and expect to complete by 2018.

Further, as per AMS 10-67 Power Transformers and Oil Filled Reactors, the strategy adopted for deteriorated bushings is to replace them where appropriate to reduce the risk of failure.

5 Risk Matrix

This high voltage bushing replacement program (chosen option – Option 3) will reduce the likelihood of those bushings failures from moderate to rare and consequences from major to moderate as shown in the risk matrix in following Figure 1 below.

The consequences become moderate as a result of the bushings being replaced with resin impregnated paper (RIP) non-porcelain bushings. These bushings will not result in porcelain projectiles during explosive failures and therefore will mitigate the health and safety risk to the personal working onsite and risk of collateral damage to other plant in the switchyard. Replacement of the bushings will reduce the failure risk from a score of II to III on the AusNet Services corporate risk matrix. Figure 1 displays the expected improvement in risks achieved through replacement of bushings.

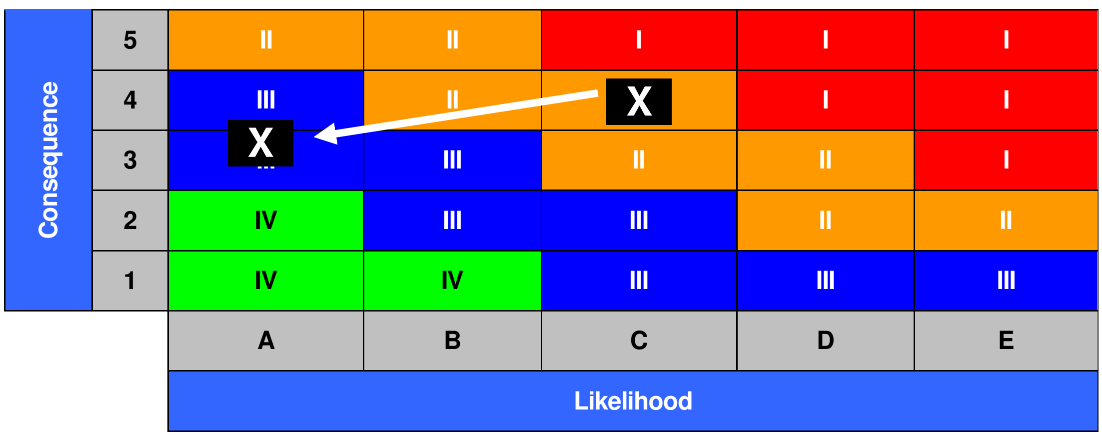

Figure 1 – Risk Matrix

6 Options

The following four options consider the benefits and consequences of complete selected bushing replacements.

6.1 Option 1 – Do Nothing

The 'Do nothing' involves routine inspection and maintenance but takes no action to refurbish or replace assets as they deteriorate and ultimately fail in service. In this option the functionality of the assets is progressively lost and service to consumers progressively declines and ultimately ceases.

In addition, this option includes the probability that the terminal failure of assets may involve explosions and fires which presents safety risks to workers within the switchyard and collateral damage risks to adjacent electrical equipment.

This option does not address AusNet Services' obligations:

- under the National Electricity Rules to maintain the quality, reliability and security of supply of prescribed transmission services;
- under the requirements of the Electricity Safety Act to operate, maintain and decommission its supply network to minimise as far as practicable the hazards and risks to the safety of any person arising from the supply network.

This option is not consistent with AusNet Services' accepted Electricity Safety Management Scheme. This implies a very high risk to the business and it fails to address key business drivers listed above in Section 3.

In respect to risk analysis for this option, the likelihood will remain moderate and consequences will remain major (i.e. as it is at the moment) if this option is chosen. Therefore do nothing is not recommended.

6.2 Option 2 – Replace on Failure

The 'Replace on failure' involves routine inspection and maintenance and replacement of assets after they fail in service. In this option consumers are periodically exposed to supply outages arising from plant failures.

In addition, this option includes the probability that the terminal failures of assets may involve explosions and fires which presents safety risks to workers within the switchyard and collateral damage risks to adjacent electrical equipment.

This option does not address AusNet Services' obligations:

- under the National Electricity Rules to maintain the quality, reliability and security of supply of prescribed transmission services;
- under the requirements of the Electricity Safety Act to operate, maintain and decommission its supply network to minimise as far as practicable the hazards and risks to the safety of any person arising from the supply network.

This option is not consistent with AusNet Services' accepted Electricity Safety Management Scheme. This implies a very high risk to the business and it fails to address key business drivers listed above Section 3.

In respect to risk analysis for this option, the likelihood will remain moderate and consequences will remain major (i.e. as it is at the moment) if this option is chosen. Therefore replace on failure is not recommended.

6.3 Option 3 – Replace on Condition

This option involves proactively replacing deteriorated 500 kV, 220 kV and 66 kV bushings as described in Section 1.1. This option will mitigate the risk of failure of bushings and the risk of transformer major failure. It will also address the program drivers listed in above Section 1.2.

Further this is the most economical option.

Option 3 ensures that the risks and issues associated with these 500 kV, 220 kV and 66 kV bushings are addressed in the most economic manner.

6.4 Option 4 – Refurbish on Condition

This option involves repairing the deteriorated bushings instead of replacement. The bushings need to be sent overseas for repair since there is no capability to repair in Australia. This would introduce an additional repair time due to the transport and will extend the outages taken on transformers. Further, the repair service providers are required to prepare special facilities in order to repair these older bushings that need to be built using antiquated methods. Therefore the repair cost of a bushing will be approximately twice the cost of a new bushing.

The bushings can only be partially repaired due to the lack of ability to fully repair older bushings manufactured using older technology. For instance the paper insulation in bushings cannot be repaired. Further, there will be no warranty given to the repaired bushings by the service provider.

In respect to risk analysis for this option, the likelihood will change to unlikely but the consequences will remain major.

Due to the all of the above reasons, the repairing of the bushings is not considered feasible; this option is therefore excluded from the financial analysis and not recommended.

7 Financial Analysis

All three options have been financially analysed[5] using an NPV model. As shown in Table 3, Option 3 (Replace Deteriorated Bushings on condition) is the most economical option.

Economic Analysis of Options ($'000s)	PV Capital Cost	PV Opex Costs	PV Community Benefits	PV Proceeds From Sales	Total PV Cost	NPV including Reg Return
Do Nothing	-	(4,454)	(18,367)	-	(22,821)	**-**
Replace on Failure	(2,336)	(1,093)	(4,508)	-	(7,937)	**48**
Replace on Condition	(3,150)	-	-	-	(3,150)	**1,122**
	-	-	-	-	-	**-**
	-	-	-	-	-	**-**

All figures are in $000's unless otherwise stated.
(nominal and discounted)

Table 3 – NPV Analysis

8 Recommended Action

The replacement on condition of deteriorated transformer bushings, Option 3, is recommended.

This program scope is to replace 9 off 500 kV, 10 off 220kV and 3 off 66 kV deteriorated bushings as outlined in Section 1.1.

9 Reference Documents

- National Electricity Rules.
- Electricity Safety Act.
- Electricity Safety (Management) Regulations.
- Work Health & Safety Act (2011).
- AMS 10-01 – Victorian Electricity Transmission Network.
- AMS 10-67 – Power Transformers Oil Filled Reactors.
- AMS 10-141 – Power Transformer Asset Health Report.

[5] The analysis does not include supply reliability consequences, impact on incentive schemes or effects on company reputation as a result of a transformer bushing failure.