OPTIONS EVALUATION REPORT (OER)

Fit OLCM to OIP Bushings

OER- n2290 revision 2.0

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Approvals

Author	Jeremy Culberg	Substations Asset Strategist
Endorsed	Debashis Dutta	Asset Analytics & Insights Manager
	Evan Lamplough	Substations Asset Manager
Approved	Andrew McAlpine	A/Head of Asset Management
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Change history

Revision	Date	Amendment
0	12/10/2021	Initial Issue
1	10/11/2021	Updated for minor wording amendments
2	12/11/2021	Formatting updates

Executive summary

Bushings are a major component of power transformers and oil filled reactors. Bushings permit the electrical conductor to pass into the high voltage equipment without making electrical contact to the surface. There are different types of bushings, however one of the most common is oil impregnated paper (OIP) bushings, which are fitted to reactors and transformers throughout Transgrid's network.

If a deteriorating OIP bushing is not detected the failure is likely to be explosive, which then leads to the complete loss of the associated reactor or transformer, through both explosive damage and fire. The expected consequences of a bushing failure event is unserved energy due to extended outages of the associated transformer or reactor, large financial costs for asset replacement and safety consequences for workers. This need is an economic benefits need and the risk of OIP bushing failure should be considered for mitigation.

Online Condition Monitoring (OLCM) can detect rapidly deteriorating bushings and therefore prevent this failure from occurring, and thus is considered for installation where it is not currently present. OLCM is currently fitted to 67% of existing assets with OIP bushings and this need considers the installation of OLCM to the remainder of the population.

The assessment of the options considered to address the need appears in Table 1.

Table 1 - Evaluated options ($ million)

Option	Description	Direct capital cost	Network and corporate overheads	Total capital cost[1]	Weighted NPV	Rank
Option A	Fit OLCM to OIP Bushings	4.74	0.64	5.38	32.6	1

Option A is the recommended solution, which is to fit OLCM to all OIP bushings that are projected to be in service beyond FY28. This option is preferred as it meets the need, it is technically feasible and has a highly positive NPV.

[1] Total capital cost is the sum of the direct capital cost and network and corporate overheads. Total capital cost is used in this OER for all analysis.

1. Need/opportunity

A bushing is a hollow electrical insulator that allows a conductor to pass safely through barrier such as the case of a transformer or circuit breaker housing without making electrical contact with it. Oil impregnated paper (OIP) bushings are fitted to many transformers and reactors across Transgrid's network. The internal insulating material comprised of paper, oil and foil layers will degrade over time due to electrical stress and also due to moisture ingress. This degradation is generally slow but can accelerate quickly such that there is only a number of hours between detection and failure. Older bushings are typically made with porcelain outer insulation though other insulating materials are also used. A life ending bushing failure is likely to be explosive in nature and is also very likely to lead the complete loss of the associated transformer or reactor, due to the subsequent fire.

When a bushing explosively fails, porcelain is ejected at great speed. The projectiles have sufficient energy to cause fatalities. Within Transgrid's history, porcelain has been found more than 50m from the failed bushing.

The key economic benefits associated with addressing this need are summarised as:

- Reduction of risk valued as a direct impact to TransGrid and consumers including:
  - Impact of expected unserved energy;
  - Safety and environmental hazards associated with a catastrophic failure.
- Avoided operating expenditure related to corrective maintenance.

Fitting of OLCM to monitor enables the repaid deterioration of bushing insulation to be detected quickly and can and has prevented loss of reactors and transformers. There is an opportunity to fit OLCM to all OIP bushings that are otherwise not due for replacement in the foreseeable period.

2. Related needs/opportunities

- Need N2404 – RP3 Transformer Refurb Program;
- Need N2423 – Yass No 3 Transformer Renewal
- Need N2422 –Tamworth Transformer Renewals
- Need N2421 – Molong No 1 Transformer Renewal

These needs include transformer renewals which mitigate the increasing bushing risk as part its scope and therefore these transformers and reactors are excluded from this need.

3. Options

3.1 Base case

The base case is to accept the increasing risk associated with OIP bushings and to consider addressing it only as part of a major renewal of the transformer or reactor, through bushing replacement of whole asset replacement.

There is no option for increased maintenance or asset monitoring which does not involve the fitting of a permanent online condition monitoring system, owing to the small window of detection available with this failure mode.

3.2 Options evaluated

Option A — Fit OLCM to OIP bushings NOSA N2290, OFS N2290

At each of the nominated locations an OLCM unit and bushing adaptors will be installed. Cabling from the OLCM units will be terminated to the condition monitoring terminal server within the control room. Bushing monitor alarms cabling will be run to the existing miscellaneous alarms panel or bay controller. The substation automation system will be updated for inclusion of new bushing monitor alarms.

A total of 246 OIP bushings across 49 transformers and reactors currently in service will require connection to a new bushing monitor. Six substations also require installation of condition monitoring PCs.

Refer to Appendix B for the list of OIP bushings requiring installation of OLCM.

Bushing failures make 35% of failures across reactors and transformers since 1979, which is consistent with externally published figures of between 25% and 40%. Fitting OLCM to the remaining OIP bushings will allow for the detection of one of the major failure modes associated with OIP bushings, thus reducing the overall risk of the oil filled reactor and transformer fleet.

Through the use of this type of OLCM, Transgrid has detected bushings where failure was imminent, and have been able to prevent the explosive failure and loss of the transformer or reactor.

Based on the success rate of OLCM detecting such failure modes, both within the TransGrid fleet, and more widely through the world, explosive bushing failures on OIP bushings are expected to be eliminated. In simple terms, the problem would be detected, the bushing replaced, and the transformer/ reactor would remain in service for the rest of its normal life. It is noted that the bushing monitoring system mitigates the risks associated with one of the major failure modes of the bushing, but does not extend the life of the bushing. Therefore bushing replacements will still be required.

From OFS-N2290A, the cost of the project is $5,818,000. With 4 sites excluded due to expected transformer renewal works to be completed before 2028, the estimated cost of the project is $5,380,000.

3.3 Options considered and not progressed

The following options were considered but not progressed:

Table 2 – Options not progressed

Option	Reason for not progressing
Bushing replacements	Replacement of older OIP bushings with modern bushings, typically resin impregnated paper (RIP) with polymer outer insulation would also address the identified increase risk of bushing failure. However bushing replacements are typically $500 thousand per primary asset and there it is not economically feasible to complete this for the remaining OIP bushing population.
Increased maintenance or inspections	The condition issues have already been identified and cannot be rectified through increased maintenance or inspections, and therefore is not technically feasible to address the need.
Elimination of all associated risk	This can only be achieved by retiring the assets on which they will be installed (the transformers and reactors), which is not technically feasible due to the requirement to maintain the existing network reliability.
Non-network solutions	It is not technically feasible for non-network solutions to provide the functionality of the equipment under this need.

4. Evaluation

4.1 Commercial evaluation methodology

The economic assessment undertaken for this project includes three scenarios that reflect a central set assumptions based on current information that is most likely to eventuate (central scenario), a set of assumptions that give rise to a lower bound for net benefits (lower bound scenario), and a set of assumptions that give rise to an upper bound on benefits (higher bound scenario).

Assumptions for each scenario for this project are set out in table 3.

Table 3 – Commercial Evaluation Weightings

Parameter	Central scenario	Lower bound scenario	Higher bound scenario
Discount rate	4.8%	7.37%	2.23%
Capital cost	100%	125%	75%
Operating expenditure benefit	Not applicable in this assessment		
Risk costs benefit	100%	75%	125%
Benefits	Not applicable in this assessment		
Scenario weighting	**50%**	**25%**	**25%**

Parameters used in this commercial evaluation are shown in Table 4.

Table 4 – Commercial Evaluation Parameters

Parameter	Parameter Description	Value used for this evaluation
Discount year	Year that dollar values are discounted to	2020/21
Base year	The year that dollar value outputs are expressed in real terms	2020/21 dollars
Period of analysis	Number of years included in economic analysis with remaining capital value included as terminal value at the end of the analysis period.	20 Years
ALARP disproportionality (primarily repex)	Multiplier of the environmental and safety related risk cost included in NPV analysis to demonstrate implementation of obligation to reduce to ALARP.	Refer to section 4.3 for details.

The capex figures in this OER do not include any real cost escalation.

4.2 Commercial evaluation results

The commercial evaluation of the technically feasible options is set out in Table 5. This assessment excludes bushings which are planned to be replaced in the current regulatory period and in the 2023-2028 Regulatory Period. Details appear in Appendix A.

Table 5 - Commercial evaluation (PV, $ million)

Option	Capital Cost PV	Central scenario NPV	Lower bound scenario NPV	Higher bound scenario NPV	Weighted NPV	Ranking
Fit OLCM to OIP Bushings	3.87	28.87	12.09	60.59	32.60	1

4.3 ALARP evaluation

Transgrid manages and mitigates bushfire and safety risk to ensure they are below risk tolerance levels or 'As Low As Reasonably Practicable' ('ALARP'), in accordance with the regulation obligations and Transgrid's business risk appetite. Under the Electricity Supply (Safety and Network Management) Regulation 2014 Section 5 'A network operator must take all reasonable steps to ensure that the design, construction, commissioning, operation and decommissioning of its network (or any part of its network) is safe.' Transgrid maintains an Electricity Network Safety Management System (ENSMS) to meet this obligation.[2]

In its Network Risk Assessment Methodology, under the ALARP test with the application of a gross disproportionate factor[3], the weighted benefits are expected to exceed the cost. Transgrid's analysis concludes that the costs are less than the weighted benefits from mitigating bushfire and safety risks. The proposed investment will enable Transgrid to continue to manage and operate this part of the network to a safety and risk mitigation level of ALARP.

Evaluation of the above options has been completed in accordance with As Low As Reasonably Practicable (ALARP) obligations. The Network Safety Risk Reduction is calculated as 6 x Bushfire Risk Reduction + 3 x other Environmental Risks + 3 or 6 x Safety Risk Reduction + 0.1 x Reliability Risk Reduction.

Results of the ALARP evaluation are set out in Table 6.

Table 6 - Reasonably practicable test ($ million)

Option	Network Safety Risk Reduction	Annualised Capex	Reasonably Practicable?[4]
A	0.18	0.42	No

The result of the ALARP evaluation is that the ALARP test is not satisfied in this case.

4.4 Preferred option

The preferred option is to fit OLCM to all OIP bushings, due to being technically feasible with a high NPV in all scenarios.

Capital and Operating Expenditure

OLCM devices are generally of a reliable construction with no required ongoing maintenance. The existing installations have had very few faults and so the opex is considered negligible and not included in this assessment.

There are no capex to opex trade-offs considered in this evaluation.

Regulatory Investment Test

The program and estimate allows for the appropriate regulatory approvals as required.

5. Optimal Timing

The test for optimal timing of the preferred option has been undertaken. The approach taken is to identify the optimal commissioning year for the preferred option where net benefits (including avoided costs and safety disproportionality tests) of the preferred option exceeds the annualised costs of the option. The commencement

2 TransGrid's ENSMS follows the International Organization for Standardization's ISO31000 risk management framework which requires following hierarchy of hazard mitigation approach

3 The values of the disproportionality factors were determined through a review of practises and legal interpretations across multiple industries, with particular reference to the works of the UK Health and Safety Executive. The methodology used to determine the disproportionality factors in this document is in line with the principles and examples presented in the AER Replacement Planning Guidelines and is consistent with TransGrid's Revised Revenue Proposal 2023/24-2027/28.

4 Reasonably practicable is defined as whether the annualised CAPEX is less than the Network Safety Risk Reduction.

year is determined based on the required project disbursement to the meet the commissioning year based on the OFS.

The results of optimal timing analysis is:

- Optimal commissioning year: 2027/28 (each site is shown in Appendix B)
- Commissioning year annual benefit: $2.23 million
- Annualised cost: $0.424 million

Based on the optimal timing, the project is expected to commence in the 2023-2028 Regulatory Period.

6. Recommendation

It is recommend to proceed with the option of fitting OLCM to OIP Bushings to DG2, at a total cost of $5.38 million.

An allowance of $350,000 to progress the project to from Decision Gate 1 (DG1) to Decision Gate 2 (DG2) is included within the total cost.

Appendix A – Option Summary

Project Description	Fit OLCM to OIP Bushings		
Option Description	N2290A Fit OLCM to OIP Bushings		
Project Summary			
Option Rank	[Option Rank] *1*	Investment Assessment Period	[Project Useful Life] *20*
Asset Life	[Asset Useful Life] *20*	NPV Year	[NPV Year] *2021*
Economic Evaluation			
NPV @ Central Benefit Scenario (PV, $m)	[Net Present Value (Standard - OER)] *28.87*	Annualised CAPEX ($m)	Annualised Capex - Standard (Business Case) *0.42*
NPV @ Lower Bound Scenario (PV, $m)	[Net Present Value (Upper Bound)] *12.09*	Network Safety Risk Reduction ($m)	Network Safety Risk Reduction *0.18*
NPV @ Higher Bound Scenario (PV, $m)	[Net Present Value (Lower Bound)] *60.59*	ALARP	ALARP Compliant? *NA*
NPV Weighted (PV, $m)	[Net Present Value (Weighted)] *32.6*	Optimal Timing	*Program – See appendix B*
Cost			
Direct Capex ($m)	*4.74*	Network and Corporate Overheads ($m)	*0.64*
Total Capex ($m)	*5.38*	Cost Capex (PV,$m)	*3.87*
Terminal Value ($m)	*0*	Terminal Value (PV,$m)	*0*
Risk (central scenario)	Pre	Post	Benefit
Reliability (PV,$m)	Reliability Risk (Pre) *24.05*	Reliability Risk (Post) *19.24*	Pre – Post *4.81*
Financial (PV,$m)	Financial Risk (Pre) *127.94*	Financial Risk (Post) *102.35*	Pre – Post *25.59*
Operational/Compliance (PV,$m)	Operational Risk (Pre) *0*	Operational Risk (Post) *0*	Pre – Post *0*
Safety (PV,$m)	Safety Risk (Pre) *8.05*	Safety Risk (Post) *6.44*	Pre – Post *1.61*
Environmental (PV,$m)	Environmental Risk (Pre) *3.10*	Environmental Risk (Post) *2.48*	Pre – Post *0.62*
Reputational ($m)	Reputational Risk (Pre) *0.58*	Reputational Risk (Post) *0.46*	Pre – Post *0.12*
Total Risk Benefit (PV,$m)	Total Risk (Pre) *163.71*	Total Risk (Post) *130.97*	Pre – Post *32.74*
OPEX Benefit (PV,$m)			OPEX Benefit *0*
Other benefit (PV,$m)			Incremental Net Benefit *0*
Total Benefit (PV,$m)			Business Case Total Benefit *32.74*

Appendix B - Sites Requiring OLCM

The following table provides a summary of the individual evaluations under this program. All assets are included in the final evaluation program unless excluded due to other planned works.

Location	Equipment Description	PIC	Number of bushing adaptors required	Number of bushing monitors required	Number of OLCM PCs required	NPV ($ million)	Optimal Timing	Excluded due to planned works
Armidale	NO3 330KV REACTOR	ETA5614	3	1		0.18	2027	
Beaconsfield North	NO.2 REACTOR & CBR BAY	TG004992	6	1		0.14	2028	
Canberra	NO4 TRANSFORMER 330/132/11KV TRANSF BAY	ETA5515	6	1		0.43	2023	
Dapto	NO1 TRANSFORMER 330/132/11KV TRANSF BAY	EC00002177	6	1		1.26	2026	
Dapto	NO3 TRANSFORMER 330/132/11KV TRANSF BAY	EC00002176	6	1		1.09	2026	
Eraring	NO2 TIE TRANSFORMER 500KV RED PHASE	EC00008615	4	1		0.39	2024	
Eraring	NO2 TIE TRANSFORMER 500KV WHITE PHASE	EC00008613	4	1		0.35	2024	
Eraring	NO2 TIE TRANSFORMER 500KV BLUE PHASE	EC00008614	4	1		0.39	2024	
Forbes	NO2 TRANSFORMER 132/66/11KV BAY	A01217/2	6	1	1			Excluded. Replaced during RP2
Forbes	NO1 TRANSFORMER 132/66/11KV BAY	A01217/1	6	1				Excluded. Replaced during RP2
Gunnedah	No1 Transformer 132KV Transformer Bay	EC00006549	6	1		0.74	2023	
Gunnedah	No2 Transformer 132KV Transformer Bay	EC00006550	6	1		0.74	2023	
Inverell	No1 Transformer 132KV Transformer Bay	EC00006738	6	1	1	0.66	2025	

Location	Equipment Description	PIC	Number of bushing adaptors required	Number of bushing monitors required	Number of OLCM PCs required	NPV ($ million)	Optimal Timing	Excluded due to planned works
Inverell	No2 Transformer 132KV Transformer Bay	EC00006737	6	1		0.86	2025	
Kemps Creek	NO2 SVC 330KV TRANSFORMER & CB BAY	EC00021960	6	1		0.50	2028	
Kemps Creek	NO6 330KV SHUNT REACTOR	ETA4672	3	1		0.20	2028	
Koolkhan	No1 Transformer 132KV Transformer Bay	ETA7368	6	1		0.11	2027	
Koolkhan	No3 Transformer 132KV Transformer Bay	EC00006547	6	1		0.41	2027	
Lismore	NO1 330KV REACTOR	EC00023558	3	1		1.09	2028	
Lismore	NO3 330KV REACTOR	EC00023564	3	1		0.15	2028	
Molong	NO 1 TRANS 132/66KV TRANSFORMER BAY	A07182/2	6	1	1			To be replaced in RP3
Mount Piper	NO1 TRANSFORMER 132/66KV TRANSF BAY	EC00006740	6	1		0.84	2023	
Munmorah	NO3 330KV TRANSFORMER BAY	ETA4291	6	1	1	0.51	2027	
Murray 330kV	No.1 Tx 330/132/11kV Transformer	ETA8449	1	1		1.03	2027	
Murray 330kV	No.2 Tx 330/132/11kV Transformer	ETA8450	6	1		1.10	2027	
Murrumburrah	No2 Transformer 132KV Transformer Bay	ETA5649	6	1		0.13	2026	
Muswellbrook	NO2 330KV TRANSFORMER BAY	EC00008975	6	1		0.99	2026	
Panorama	NO2 TRANSFORMER 132/66/11KV TRANSF BAY	EC00003261	3	1		0.79	2025	
Parkes	NO2 TRANSFORMER 132/66/11KV BAY	EC00023197	6	1	1	0.65	2023	

Location	Equipment Description	PIC	Number of bushing adaptors required	Number of bushing monitors required	Number of OLCM PCs required	NPV ($ million)	Optimal Timing	Excluded due to planned works
Regentville	NO1 330/132 TRANSFORMER BAY	EC00008976	6	1	1	1.09	2024	
Regentville	NO2 330/132 TRANSFORMER BAY	EC00025071	6	1		0.55	2024	
Sydney East	NO1 REACTOR 132KV	EC00014686	3	1		0.55	2027	
Sydney South	41 BEACONSFIELD SERIES REACTOR BAY	TG007188	3	1		0.07	2028	
Sydney South	NO.2 330KV REACTOR BAY	ETA7377	3	1		0.10	2028	
Sydney South	NO.3 330KV REACTOR BAY	ETA7427	3	1		0.11	2028	
Sydney West	NO5 TRANSFORMER 330/132/11KV TRANSF BAY	ETA6128	6	1		0.68	2026	
Tamworth 330kV	No1 Transformer 330KV Transformer Bay	A08692/2	3	1				To be replaced in RP3
Tamworth 330kV	No2 Transformer 330KV Transformer Bay	EC00008146	6	1				To be replaced in RP3
Tamworth 330kV	No3 Transformer 330KV Transformer Bay	ETA4027	6	1		0.34	2024	
Taree	NO1 132KV TRANSFORMER BAY	ETA8829	6	1	1	1.69	2023	
Taree	NO2 132KV TRANSFORMER BAY	ETA8828	6	1		1.67	2023	
Taree	NO3 132KV TRANSFORMER BAY	EC00017635	6	1		1.63	2023	
Taree	NO4 132KV TRANSFORMER BAY	EC00020023	6	1		1.42	2023	
Tenterfield	No1 Transformer 132KV Transformer Bay	A08127/1	6	1	1	0.97	2028	
Tenterfield	No2 Transformer 132KV Transformer Bay	A08127/2	3	1		0.97	2028	

Location	Equipment Description	PIC	Number of bushing adaptors required	Number of bushing monitors required	Number of OLCM PCs required	NPV ($ million)	Optimal Timing	Excluded due to planned works
Tumut 132kV	No1 Transformer 132KV Transformer Bay	EC00006548	6	1		1.21	2023	
Tumut 132kV	No2 Transformer 132KV Transformer Bay	ETA5309	6	1		2.03	2023	
Vales point	NO2 330KV TIE TRANSFORMER BAY	EC00025076	6	1		0.52	2027	
Vales Point 330kV	NO1 330KV TIE TRANSFORMER BAY	ETA4686	6	1		0.50	2027	
Wallerawang 330kV	NO4 TRANSFORMER 330/132/11KV TRANSF BAY	TG013244	3	1		0.27	2028	
Wellington	330KV NO. 1 REACTOR BAY	EC00009533	3	1		0.37	2026	
Wollar	NO1 500/330/11KV TRANSFORMER RED PHASE	TG006027	4	1		0.06	2027	
Wollar	NO1 500/330/11KV TRANSFORMER BLUE PHASE	TG006028	4	1		0.06	2027	
Total to progress			**246**	**49**	**6**	**32.6**		