Investment Decision Pack

A9.13 – Through-wall & floor bushing

December 2019

As a part of the NGET Draft Business Plan Submission

nationalgrid

Engineering Justification Paper; Non-Load Related Through-Wall & Floor Bushings			
Asset Family	Through Wall/Floor Bushings		
Primary Investment Driver	Asset Health (Non-Lead Assets)		
Reference	A9.13		
Output Asset Types	• Through Wall Bushings • Through Floor Bushings		
Total Cost for RIIO-T2 Period	£14.301m		
Delivery Year(s)	2021 - 2026		
Reporting Table	C2.2A		
Outputs included in T1 Business Plan	No		
Spend Apportionment	**T1**	**T2**	**T3**
	£0m	£14.299m	£0.002m

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1. Executive Summary

This paper justifies a spend of £14.3m to replace [redacted] through wall/floor bushings over the five-year period 2021-2026 and to further improve our understanding of asset deterioration and condition using forensic asset health analysis (post-mortem) of ex-service assets.

The T2 unit cost of [redacted] of forensic analysis costs, justifies the £14.3m identified to replace [redacted].

Replacement candidates are identified based upon asset health condition indicators and known asset family issues. Planned replacement is also based on the Anticipated Asset Life (AAL).

Three options have been identified; do nothing, refurbishment and replacement. Do nothing is not viable as this would lead to safety and reliability breaches due to catastrophic failure of the assets. There is no viable refurbishment option either. Due to the old age of the assets, refurbishment can only be carried out using information only available from the original manufacturers, most of whom are no longer in existence. Replacement is the only remaining option, and therefore the chosen option, with a CBA identifying the NPV of this option.

Our stakeholders have told us that safety and reliability are important to them and identifying interventions for through wall/floor bushings to effectively manage safety, environmental and operational issues ensures that we continue to address this expectation.

2. Introduction

Through wall/floor bushings provide a means of safely passing high voltage busbar connections through solid surfaces such as the external or internal walls of substation buildings. In some cases, they also incorporate the measurement functionality of instrument transformers adding to their criticality for operation & protection of the transmission network. They are distinct from transformer bushings, GIS line end bushings or oil circuit breaker bushings which are not addressed in this paper.

Figure 1 shows an example of a through wall bushing:

Figure 1 – Photograph of a 400kV through wall bushing

Our stakeholders have told us that safety and reliability are important to them. Our asset management approach to identify interventions for through wall/floor bushings to effectively manage safety, environmental and operational issues ensures that we continue to provide a safe and reliable transmission network for our stakeholders and consumers.

Potential Safety Implications of Failure

Failures of through wall/floor bushing failures are typically of an explosive (catastrophic) nature resulting in porcelain dispersal across the substation with the associated potential for safety risks to personnel and consequential damage to adjacent assets. NGET has experienced such failures and applies Risk Management Hazard Zones (RMHZ) around equipment discovered to be in poor asset health to control access into the equipment and to keep people safe should a failure occur. The photographs forming Figure 2 below demonstrate the various aspects of such a catastrophic failure of a 132kV oil impregnated paper through wall bushing.

Figure 2a - External burning & carbonisation of substation wall

Figure 2b - Porcelain fragments ejected up to 30m

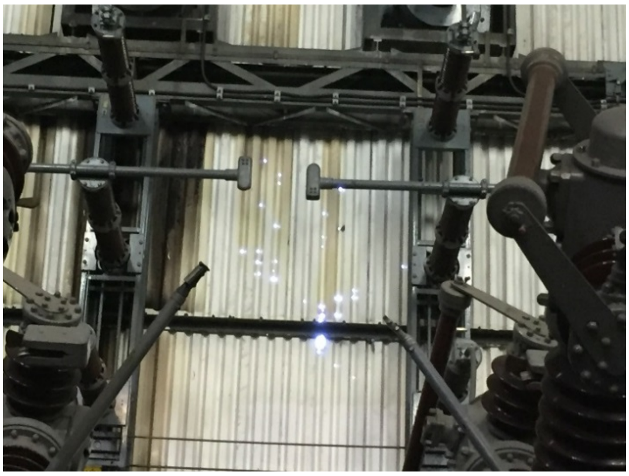

Figure 2c - Perforated substation wall

3. Performance at RIIO-1

3.1 T1 Allowances

A total of [redacted] through wall/floor bushings were planned to be delivered during T1. This volume reduced to [redacted] units due to [redacted] units being delivered prior to the start of T1 and our ongoing condition monitoring confirming [redacted] individual units to be in a better condition than anticipated. In total [redacted] fewer through wall/floor bushings than expected required replacement.

3.2 T1 Outturn performance - volume

The actual and forecast delivery for T1 is shown in Figure 3.

	RIIO-T1					
Through Wall Bushings - Total	**T1 Allowances**	**T1 Actuals**	**T1 Forecast**	**T1 (all years)**	**Annual average**	**Annual av (first 6 years)**
Total volume	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Figure 3 – T1 Allowances

3.3 Outturn performance – costs

Prior to T1 the average unit delivered cost of replacement was £[redacted] /phase within which there are a range of actual costs which are influenced by factors such as voltage rating and the number of units to be replaced (i.e. single-phase replacement or 3 phase replacement).

The average unit cost of delivery during T1 has been £[redacted] /phase. The [redacted] aligning bushing replacements with other switchgear projects, and, in some cases, deploying ex-services "grey spare" bushings in substitution for newly purchased units.

The co-ordination and alignment with other projects has delivered savings on mobilisation, site set-up, project management and commissioning resource. In-house delivery using Operations teams has also proven to be cost-effective.

3.4 T1 performance versus allowances

Due to the nature of delivery of these assets (they are bundled with lead assets to achieve greater efficiencies) it is not possible to accurately state T1 costs until all the projects are complete, and final costs analysed.

	RIIO-T1		RIIO-T2	RIIO-T1	RIIO-T2
Through-Wall & Floor Bushing - Total	**T1 Allowances**	**T1 (all years)**	**T2 forecast**	**Annual average**	**Annual average**
Total cost (£m)	59		14.3		3
Total volume	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Cost per unit volume	[redacted]		[redacted]		[redacted]

Figure 4 – T1 performance

We are on track to deliver the [redacted] units planned in T1, [redacted]

4. Investment Need

4.1 Investment Drivers

The construction of indoor AIS substations was a common practice at 132kV up to, and including, 400kV from the mid-1960's until the early 1970's. There are [redacted] through wall/floor bushings on the transmission network with over half of the units installed at 132kV or below. Figure 5 shows the asset profile of through wall/floor bushings based on year installed.

Condition is the main investment driver for intervention on through-wall bushings, driven mainly through the age of the asset. Condition is also assessed through assessment of the oil held within the bushing. Dissolved Gas Analysis (DGA) of the oil also drives the requirement to intervene, which may be required on an asset regardless of age.

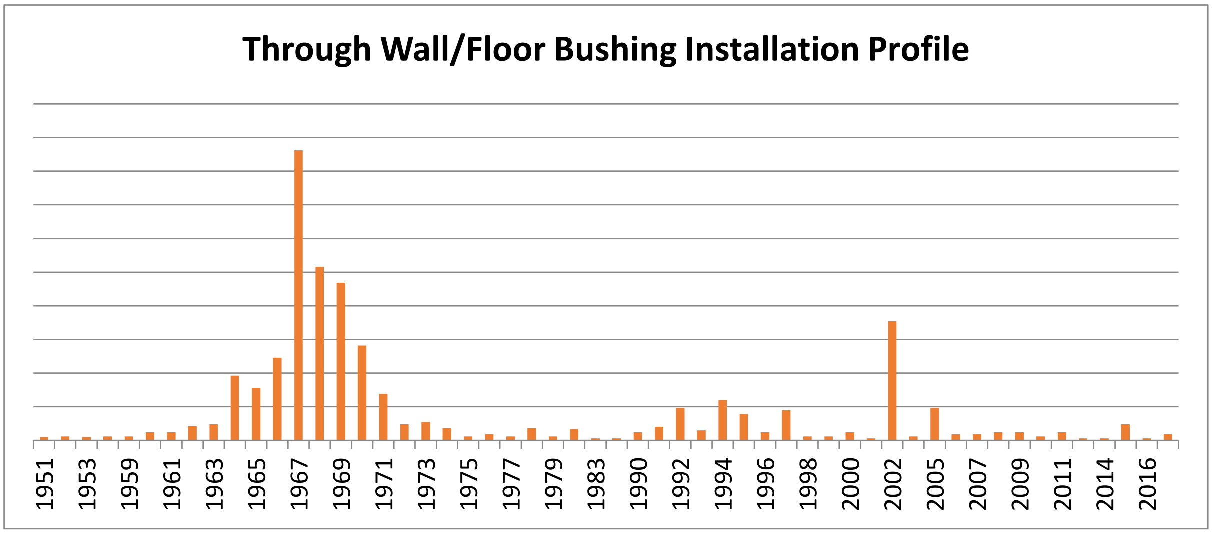

Figure 5 - Through wall/floor bushing installation profile

4.2 Approach to estimating RIIO-2 volumes

This section sets out the approaches used to identify required interventions in the RIIO-2 period.

4.2.2 Asset Health Assessment

The annual asset health review takes into consideration equipment age and health to determine the condition of each asset. The results from each condition technique is categorised as defined in the Technical Guidance Note TGN(E) 082, and replacement priorities are determined through the policy EPS 12.00.

An intervention is determined for through wall and floor bushings on condition. A variety of techniques are employed to assess the condition of these assets, to indicate the onset and development of asset family issues, and to inform their Anticipated Asset Life (AAL) which is presently 50 years. These techniques are categorised as 'non-intrusive condition assessments' which are made whilst in-service, when out of service due to a lead asset outage, or intrusive forensic analysis on equipment which has been removed from the system.

Applying non-invasive techniques at defined intervals allows us to identify individual assets which are in poor condition and, to some extent, identify developing family issues. Individual assets which are found to fall outside defined condition parameters captured in our policy are targeted for intervention.

4.2.3 Forensic Analysis

Forensic analysis (intrusive/ destructive) on de-commissioned assets allows us to confirm the findings of non-intrusive techniques and gives the opportunity to detect additional failure modes and family issues from which we can build a more comprehensive picture of the contribution of defects, faults & failure to the AAL. Post-service analysis has been, and will continue to be, an important tool in managing these asset types and improving our understanding of their asset health and deterioration.

4.2.4 Condition Assessment

The following are the main non-invasive techniques that are presently deployed:

- Visual checks – oil leakage, corrosion, cracked or broken insulation, signs of electrical discharge and integrity of external fittings
- Audible noise – human detection of electrical discharge within the insulation of the through wall/floor bushing
- Radio Frequency Interference – radio detection of electrical discharge within the insulation
- Thermography – detection of heat from increased resistive load on insulation
- Oil sampling for dissolved gas analysis and moisture content

Diagnostic electrical testing is also used (capacitance, loss angle and partial discharge tests) but there are issues in achieving consistent, accurate results during site tests due to atmospheric conditions and adjacent live circuits. These tests are more useful when conducted prior to an asset entering service (factory acceptance testing) and when an asset has been removed from service.

4.2.5 Innovation

On a limited scale, we have explored more innovative online condition monitoring technology. This has allowed the refinement of replacement planning based on the condition which has helped to better inform the T2 plan as it has provided an insight on asset health. As can be seen from the installation profile in figure 5, the volume of bushings which require replacement in T3 could be significantly larger than T2. In our condition monitoring justification, we include an investment in enhanced monitoring for bushings, which will allow us to find innovative methods to manage the risk on bushings for the T3 period.

4.3 RIIO-T2 Required Volumes

The T2 plan has [redacted] through wall bushings identified for intervention, [redacted] of the total population.

TWB Voltage	Exceeding AAL	Less than AAL
400kV	[redacted]	[redacted]
275kV	[redacted]	[redacted]
132kV	[redacted]	[redacted]
<132kV	[redacted]	[redacted]
Total	[redacted]	[redacted]

Figure 6 - Summary of the asset replacement volume

Figure 6 shows a breakdown of the bushings, by voltage, identified for intervention from the asset health and condition assessment process detailed earlier. [redacted] bushings are expected to exceed their anticipated asset life before the end of T2. [redacted] of these are already showing poor health through their DGA results. There are a further [redacted] assets which are not expected to reach their anticipated asset lives by the end of T2, but have DGA results which highlight an intervention will be needed within the T2 period. Appendix 2 shows the DGA results for these [redacted] assets as justification for these assets to be replaced.

5. Optioneering

During the optioneering stage, various factors have been considered when determining the options. Each option is studied and a cost benefit analysis (CBA) is carried out to support the decision. There are no non-network or whole system solutions applicable in this area.

5.1 Options Considered

5.1.1 Do Nothing (not viable)

An option to do nothing across the through wall/floor bushing asset families would leave assets on the system, beyond their expected asset life, or with known family/type issues. These assets would be left to fail, after which they would be replaced.

As there is a known history of catastrophic failures of bushings, this option has not been considered further due to the potential safety, environmental and network reliability impacts these failures would cause. This would also have an impact on the deliverability of other planned work in T2 on the network.

Costs have not been included in the CBA for this option.

5.1.2 Refurbishment (not viable)

Refurbishment of through wall/floor bushings, while technically feasible, requires design information, drawings (of both the assembly and the sub-components) and procedures which are only available to the original manufacturer. Given the age of the bushings, most of the original manufacturers are no longer trading and the relevant design information is unavailable making refurbishment impossible.

Costs have not been included in the CBA for this option.

5.1.3 Replacement

New bushings, designed and tested to modern standards are available and their deployment removes the safety, environmental and operational risks associated with bushing failure for the anticipated life of the new asset.

The replacement of through wall/floor bushings would be completed mostly in-house by the Operations teams which has proved to be a cost-efficient means of delivery in T1. The exceptions will be those cases where safety & efficiency can be better achieved by bundling bushing replacements with other work.

Replacement is the only viable option for all through wall/floor bushings.

5.1.3.1 Costs

T2 Unit Cost

The average cost of a bushing replacement is £[redacted] /phase based on T1 delivered costs.

Total cost for option

In addition to the cost for replacing [redacted] units, £[redacted] has been identified for forensic asset health analysis of removed units. This will further improve our understanding of the assets and their condition leading to a less reactive approach to replacement in future price controls.

Assets	Volume	Cost
400kV	[redacted]	[redacted]
275kV	[redacted]	[redacted]
132kV	[redacted]	[redacted]
<132kV	[redacted]	[redacted]
Forensic Analysis	[redacted]	[redacted]
TOTAL	[redacted]	£14.3m

Figure 7 – T2 cost & volume summary

5.1.3.2 Benefits

This option provides planning and deliverability benefits since it does not rely on short-term response and spares availability which would be required for the 'do nothing' option. There are environmental and safety benefits as the risk of catastrophic failure is minimised with this option. Network risk and reliability, a key requirement of our stakeholders, can also be maintained with this option.

5.1.3.3 Overall Assessment

The results of our CBA analysis are set out in the table below:

Option	T2 investment (undisc, £m)	Total investment (undisc, £m)	NPV (£m, disc)	NPV inc monetised risk (£m, disc)
Do Nothing	An option to do nothing across all the through wall/floor bushing scope would mean to leave assets on the system, beyond their expected asset life, or with known family/type issues and replace on failure. As there is a known history of catastrophic failures of bushings, this option has not been considered further.			
Refurbishment	Refurbishment of through wall/floor bushings, while technically feasible, typically requires the original manufacturer to perform the work due to the need for details and drawings of the assembly and original components. Due to the lack of information and most original manufacturers no longer trading, refurbishment is not considered possible.			
Replacement	-14.300	-14.300	-12.521	-12.521

Figure 8 – Results of CBA analysis

The chosen option is the planned replacement of [redacted] bushings in T2. This provides the only solution which meets safety, environmental, reliability, risk and stakeholder requirements.

6. Key risks and Uncertainty

6.1 Risks

6.1.1 Civil Structures

Based on our experience of T1, civil structures have not required to be intervened on due to interventions on bushings. There is a risk in T2 that existing structures for the replacement of through wall/floor bushings are not suitable for reuse.

6.1.2 Busbar and busbar connectors

At this early stage, each project is not fully developed therefore it is impossible to fully condition assess the small additional components that may need to be replaced. Due to their relatively small cost an assumption has been made that they will be replaced at this stage.

6.1.3 Outage Availability

There have been instances where outages have been cancelled by the Electricity System Operator to maintain SQSS compliance due to unplanned faults in the network. This is an ongoing risk that we don't expect to increase or decrease in T2.

6.2 Uncertainties

The T2 volumes have been determined using the asset management principles set out in this report. There is a risk that future annual asset health reviews, prior to the start of T2 reveal more assets in poor condition that need replacing.

7. Conclusion

This report explains the type of assets involved, and their performance on the transmission network. It explains in detail the safety implications of how these assets typically fail, and why a proactive intervention is necessary. We detail the total volume of assets on the network, and the small percentage that is planned to be intervened on in the T2 period.

Two of the three options considered (do nothing and refurbishment) are not viable for different reasons. The only viable option remaining is replacement of these assets based on their condition. A CBA has been carried out, but there are no viable options to be compared against.

It has been demonstrated that the most efficient solution is to replace [redacted] bushings in T2. [redacted]

8. Appendix 1 – Asset Listing

Through Wall Bushing interventions

TWB Voltage (kV)	Units beyond expected life	Units less than expected life with condition driver
400kV	[redacted]	
275kV		
132kV		
<132kV		
Total		

This list has been redacted

Appendix 2 – DGA Analysis of through-wall bushings

The following table is an extract from our policy which highlights the minimum standards for through-wall bushings. Category 1 and 2 results indicate that the bushing needs to be replaced.

Category	Hydrogen (H_2) ppm	Acetylene (C_2H_2) ppm	Ethane (C_2H_6) ppm*	Methane (CH_4) ppm*	Ethylene (C_2H_4) ppm*	Moisture (H_2O) ppm <u>Adjusted to 20°C**</u>
1	>1000	>10	>500	>200	>100	>30
2	500 to 1000	2 to 10	400 to 500	150 to 200	50 to 100	25 to 30
3	300 to 500	0.3 to 2	50 to 400	30 to 150	10 to 50	20 to 25
4	<300	<0.3	<50	<30	<10	<20
5	Assets fitted for less than 25 years					

The following are the [redacted] bushings that exceed these limits and need replacing solely on these results alone:

This list has been redacted