SSEN Transmission

RIIO-T2 Business Plan: T2BP-EJP-0027 rev 1.1

Sloy Substation Works

Engineering Justification Paper

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1 Executive Summary

Our paper A Risk Based Approach to Asset Management[1] sets out our approach to network risk and how we subsequently identify assets that require intervention to limit the rise of risk over the RIIO-T2 period.

This paper identifies the need for intervention on the Grid transformers (GTs) at Sloy. The primary driver for the scheme is the asset condition of the existing transformers.

Following Ofgem's published Draft Determination in July, we have re-assessed the need in conjunction with an independent consultant, and the options for this project. There is also an additional option for do nothing and for a replacement of GT3 only. The proposed option has not changed as a result of this review.

Following optioneering and detailed analysis, as set out in this paper, the proposed scope of works is;

- Construction of a new site compound near the existing substation at the power station. An offline build of GT1, GT2, GT3 and GT4 at the new site.
- At the new substation install four 132kV circuit breakers, and eight 11kV circuit breakers.
- The existing GT1, GT2, GT3 and GT4 and associated equipment at the existing substation are to be removed.
- Tower and gantry works are required for connection to the OHL, and 11kV cables will be installed to connect to the power station.

This scheme will [redacted] and will deliver the following outputs and benefits during the RIIO-T2 period:

- A long-term monetised risk benefit [redacted];
- A reduction of network risk calculated as R[redacted]; see Section 5 for details; and,
- Improved operational flexibility and resilience in line with our goal to aim for 100% transmission network reliability for homes and businesses.

The Sloy substation Works project is not flagged as eligible for early or late competition due to it being under Ofgem's £50m and £100m thresholds respectively.

[1] A Risk Based Approach to Asset Management

Name of Scheme/Programme	Sloy Substation Works
Primary Investment Driver	Asset Health (Non-Load)
Scheme reference/ mechanism or category	SHNLT204
Output references/type	NLRT2SH204
Cost	[redacted]
Delivery Year	RIIO-T2 Period
Reporting Table	C0.7_Non_Load_Master_Data
Outputs included in RIIO T1 Business Plan	No

2 Introduction

This Engineering Justification Paper sets out our plans to undertake refurbishment works of existing assets during the RIIO-T2 period (April 2021 to March 2026). The planned work is at Sloy substation, the location of which is shown in Figure 1 on the next page.

The Engineering Justification Paper is structured as follows:

Section 3: Need

This section provides an explanation of the need for the planned works. It provides evidence of the primary and, where applicable, secondary drivers for undertaking the planned works. Where appropriate it provides background information and/or process outputs that generate or support the need.

Section 4: Optioneering

This section presents all the options considered to address the need that is described in Section 3. Each option considered here is either discounted at this Optioneering stage with supporting reasoning provided or is taken forward for Detailed Analysis in Section 5.

Section 5: Detailed Analysis

This section considers in more detail each of the options taken forward from the Optioneering section. Where appropriate the results of Cost Benefit Analysis are discussed and together with supporting objective and engineering judgement contribute toward the identification of a selected option. The section continues by setting out the costs for the selected option.

Section 6: Conclusion

This section provides summary detail of the selected option. It sets out the scope and outputs, costs and timing of investment and where applicable other key supporting information.

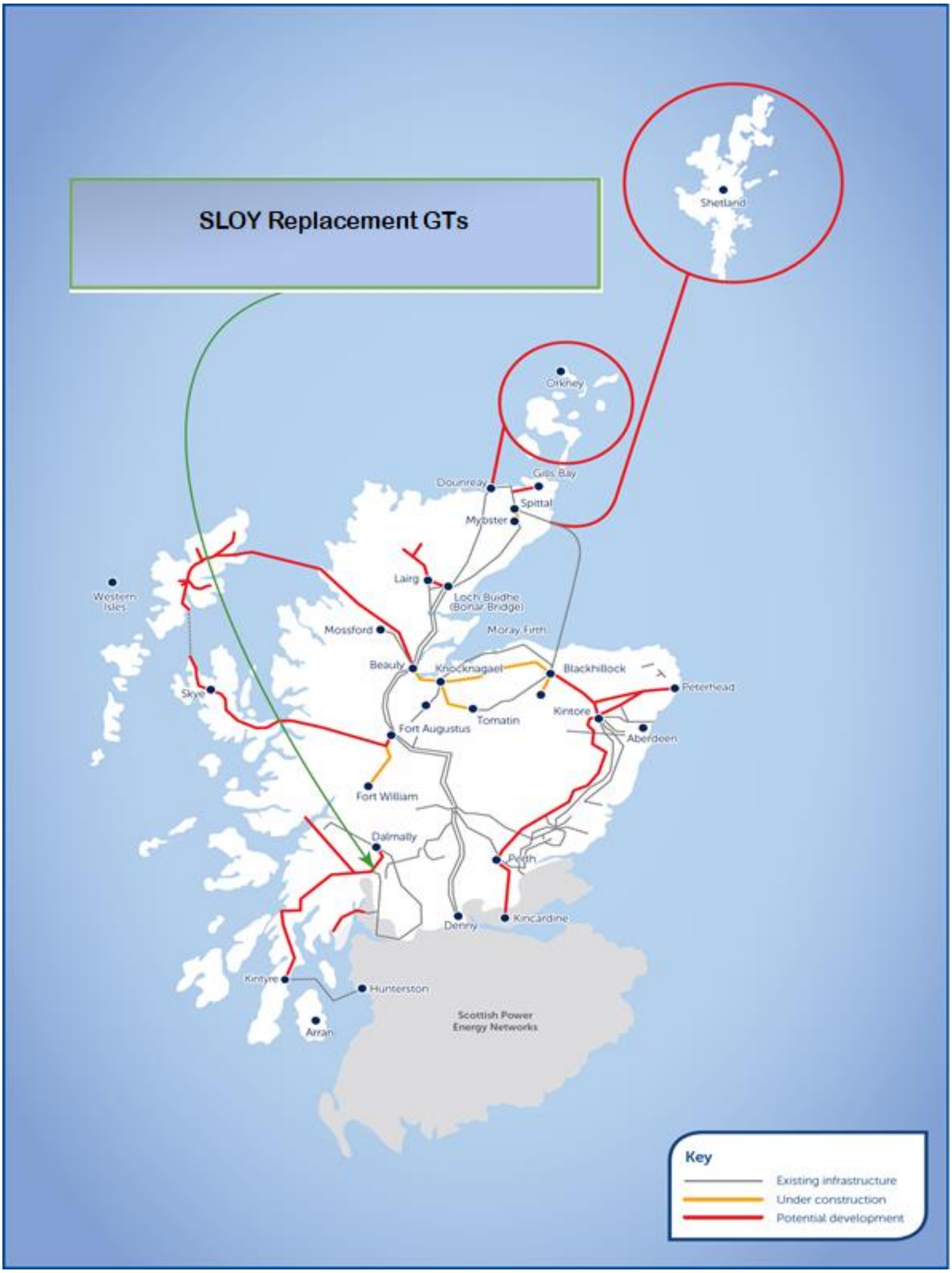
Section.7 Price Control Deliverables and Ring Fencing

This section provides a view of whether the proposed scheme should be ring-fenced or subject to other funding mechanism.

Section 8: Outputs included in RIIO-T1 Business Plan

This section identifies if some or all the outputs were included in the RIIO-T1 Business Plan and provides explanation and justification as to why such outputs are planned to be undertaken in the RIIO-T2 period.

Figure 1. Map showing the Sloy substation works on a map of SHET network



2.1 Post Draft Determination Update

The Ofgem Draft Determination stated that the need case was not clear and unambiguous for the replacement of the GTs at Sloy Power Station, and that they consider it is possible to extend the life of the transformers into the RIIO T3 period with additional condition monitoring.

This document has been updated in response to the Draft Determination on the RIIO T2 Business Plan submission; further work has been undertaken to confirm the asset condition and 2 additional options have been considered to enhance the analysis.

2.1.1 Asset Condition Review

Polaris Diagnostics & Engineering Ltd was commissioned to undertake a review of our Asset Condition Report (ACR) and historical oil data for the transformers at Sloy. This was an assessment of the same data used to write the original asset condition report; the justification paper has been updated to clarify the need.

The Polaris reports, summary report provided in Appendix B, conclude that there is evidence of accelerated ageing of the solid insulation of the transformers and this will continue throughout RIIO T2. There is a history of 11kV busbar faults at Sloy which has impacted on the GTs and evidence indicates there is a type defect manifesting across all four transformers. There is a clear need for intervention on the assets to mitigate the risk of failure within the RIIO T2 period.

2.1.2 Consideration of Additional Options

Two additional options have been considered within the revised report. These have been included as a result of comments within the Ofgem draft determination.

One is a “do minimum” option with additional monitoring on the existing transformers rather than replacement. This option does not address the concerns raised by the ACR and the Polaris report, and will not help “extend” the life of the GTs to the RIIO T3 period.

The other additional option was to consider the replacement of GT3 only. This addresses the immediate concern on the GT in the worst condition, however does not address the high likelihood of failure in the RIIO T2 period associated with the remaining three GTs.

3 Need

This section provides an explanation of the need for the planned works. It provides evidence of the primary and, where applicable, secondary drivers for undertaking the planned works. Where appropriate it provides background information and/or process outputs that generate or support the need.

3.1 Background

Sloy Power Station is located on the western shore of Loch Lomond near Inveruglas, Argyll and Bute. The site is located within the Loch Lomond and The Trossachs National Park and can be accessed from the A82.

Figure 2. Geographic Diagram showing Sloy Power Station and the proximity to Loch Lomond

Sloy Power Station was constructed in 1950 and has a total capacity of 152.5MW. The SHE Transmission substation is located to the rear of the power station building and is a four transformer site that provides connections to the local DNO and Sloy Power Station. Two transformers provide direct connections to the power station (GT2 and GT3) and two transformers serve both the power station and local distribution network (GT1 and GT4). Sloy GSP supplies over 600 customers on the local distribution network. The four transformers are 132/11kV 25/50MVA (ONAN/OFAF) units, which were installed between 1995 and 1998.

The SHE Transmission substation at Sloy Power Station is not the same site as Sloy switching station, which is located to the south-west of the power station. The transformers at the power station are connected to Sloy switching station via 132kV OHL and underground cable circuits.

3.2 Asset Need

An asset condition report[2] (ACR) has been prepared for this substation which identified a need for intervention. The ACR draws upon information from a variety of sources with the key points summarised below. In addition to the ACR, post submission of the RIIO T2 business plan we commissioned Polaris Diagnostics & Engineering Ltd to undertake a Level 1 condition assessment of the transformers at Sloy Power Station. The Polaris condition assessment was based on a review and independent assessment of the historic oil data (including a recent oil sample taken from GT1 in February 2020) and the ACR. Summary reports from Polaris for each of the four transformers at Sloy are included in Appendix B.

Polaris Review

Based on the review, Polaris concluded that it is likely there is a type defect manifesting in these transformers, as characterised by accelerated ageing of the paper insulation, which is detected by increasing levels of 2-Furfural (2-FAL) in all four 132/11kV transformers. The root cause of this has not yet been determined.

Polaris state that there is a high likelihood that the condition of the transformers will deteriorate during the RIIO T2 period, resulting in failure of GT3 and possible failure of GT1, GT2 and GT4, based on the assessment of the historical and current asset condition data. Further to this Polaris make the following end-of-life predictions:

- GT3 – would predict that "end of life" would be reached at the latest in the year 2026. The transformer has 6 years of operational service life remaining, which is within the RIIO T2 period.
- GT4 – would predict that "end of life" would be reached at the latest by the year 2030.

[2] Sloy Power Station Asset Condition Report (Rev 1.10) [T2BP-ACR-0011]

- GT1 – would predict that "end of life" would be reached at the latest by the year 2032.
- GT2 – would predict that "end of life" would be reached beyond the RIIO T2 period.

These end-of-life predictions are based on measured 2-FAL and the resultant estimated Degree of Polymerisation (DP) over the past 20 years. The trend of the estimated DP can be extrapolated to predict the "end of life". The end of life predictions are based on the observable rate of ageing and an assumption that there is no deviation in that rate or that the transformer is not subjected to external mechanism failure. Graphs showing the trend of estimated DP are included in Appendix C.

The effects of dilution due to oil top-ups or variation in load act to mask the true condition of the insulation. This introduces a significant concern that the true end of life for the transformers will be earlier than the linear predicted "end of life" from the DP trends.

There has been a number of recorded 11kV busbar faults across the GTs, as detailed in the ACR. These numerous faults could have the effect of mechanically impacting on the integrity of the transformer windings. When combined with a degrading insulation structure the transformer can become susceptible to an instantaneous failure resulting from a short circuit fault on the 11kV busbar. Polaris has highlighted the increased risk of instantaneous failure of these transformers due to reduced through fault withstand capability caused by a history of faults on the 11kV busbars and winding shrinkage caused by paper insulation ageing.

Although the transformers are considered to be within their working life, the DP trends show that the condition of the transformers are deteriorating quickly, and that the DP will continue to reduce over time. The trends, coupled with the history of 11kV busbar faults, have shown that we need to intervene on these assets in the T2 period ahead of the assets reaching the end of their working life. The transformers were only installed between 1995 and 1998 and the evidence is showing that they are in a significantly worse condition than they would be expected to be at this age. The accelerated ageing of the paper insulation across all four of the GTs indicates there is a type defect manifesting in the transformers. Intervention on all transformers would be required to remove the type defect risk.

Asset Condition Report

The conclusions from Polaris are consistent with the conclusions and recommendations of the ACR where we noted that all four transformers were found to be displaying increasing 2-FAL trends, which is an indication of solid insulation ageing. The absolute 2-FAL content of these transformers and their rate of increase is high enough to raise concerns about the condition of the solid insulation and its ageing rate. We noted that all four transformers are at various stages of deterioration.

Because the four transformers at Sloy are of the same type and vintage, are displaying similar symptoms, and are subject to similar load and duty cycles this indicates that all four transformers are subject to the same accelerated ageing mechanism leading to likely future failure mode.

We subsequently concluded that Sloy Power Station GT1, GT2, GT3 and GT4 require intervention to prevent the temporary and/or permanent loss of these units.

Black Start Capability

Sloy Power Station is a contracted generator within the Black Start strategy for the network in Scotland. It plays an important part of the local joint restoration plan, as well as the joint SHET/NGESO restoration plan for Scotland. Sloy Power Station is expected to be utilised alongside other power stations to initially energise the local network and allow regional demand to be restored. It also contributes significantly in SHET power island, which in turn assists with the overall recovery of the Main Interconnected Transmission System (MITS) for GB.

In order to act as a power island for Black Start, three of the generating units and three of the GTs at Sloy need to be available. Any failure of one of the GTs at Sloy would compromise the Black Start strategy, and any planned maintenance on the transformers would need to be deferred. Any impact on adjacent GTs as a result of a failure of one of the transformers would severely impact on the Black Start strategy.

Further Issues

Careful consideration of the existing site is required under option assessments, as it presents a number of inherent risks due to its location within a national park and the compact nature of the site. The power station is located within 100m of Loch Lomond, which could lead to significant environmental damage should an oil leak contaminate the water courses. There is currently an operational constraint at the existing site due to the close proximity of the assets. In order to undertake maintenance on an existing bay at Sloy substation, a proximity outage is required on the adjacent bay.

The existing site at Sloy is very compact with four grid transformers and associated equipment fitted into a small space to the rear of the power station. The proximity of assets to each other and the power station building presents operational challenges and increased risks, including fire separation and the risk of collateral damage to other healthy transformers and the Sloy Power Station building. The risk to the power station posed by the transformers in their current location has been regularly highlighted by SSE’s insurers in the past. Two of the GTs at Sloy Power Station connects to the local distribution network, as well as the large Sloy hydro generators. These GTs therefore feed the local customer demand in this area, and connect local small embedded generators.

Due to the constraints at the existing site, any catastrophic failure of a transformer would drive the requirement to establish a new substation adjacent to the site, as any permanent replacement solution is unlikely to be able to be located within the existing substation. Given the location within the national park, this will require significant time to plan, develop and construct the new substation. During this time consideration would need to be given to a temporary solution to ensure interrupted demand could be restored. There are over 600 customers on the local distribution network connected to Sloy, and less than 25% of these could be restored via distribution network backfeeds. The remaining customers would have to be restored utilising mobile generators. The generation could be constrained for a significant period of time. This lengthy outage could impact on the Black Start strategy as Sloy Power Station plays an important part in both local and wider restoration plans.

Multiple assets and facilities are shared between SHE Transmission, the local DNO and local generation customers. There is no SHE Transmission owned switchgear at Sloy Power Station, and so protection and isolation is reliant on remote sites (Sloy Switching Station) and third parties (local DNO and local generation customers). This is not in line with current practices and guidelines. Therefore, it is recommended in any replacement works that the separation issue is addressed through the installation of 11kV circuit breakers. Protection replacements should take place when replacing the associated transformer.

Asset Need Conclusion

The ACR and report from Polaris have demonstrated a clear and unambiguous need to undertake intervention works on the Sloy transformers to prevent the temporary or permanent loss of these units. All four transformers are displaying symptoms of internal overheating and solid insulation ageing. The transformers are at various stages of deterioration. Ageing of this nature is permanent and cannot be reversed without major intervention. Any intervention other than replacement would require extensive outages, the removal of the transformers from site, and has no guarantee of success.

Increased oil sampling and the addition of monitoring equipment will do nothing to restore the condition of the assets or affect their rate of deterioration, and therefore does not extend the life of these assets.

Oil intervention will not halt the ageing paper insulation of the transformers and will simply serve to mask the issue as it will affect the 2-FAL concentrations in the oil. This is a recommendation from Polaris as part of their assessment.

GT3 has a clear driver for a need to intervene within the RIIO T2 period.

While the end-of-life predictions from Polaris for GT1 and GT4 are just beyond the T2 period (GT2 is showing similar trends to the other GTs, albeit it at an earlier stage), it is important to consider that the extrapolation of end of life is not an exact science.

The end of life predictions for GT1, GT2, GT3, and GT4 are derived from transformer oil sampling measured data Furans 2-FAL measurement converted by the accepted Chengdong algorithm method to derive estimated DP of the insulation system. The estimated DP values over time were plotted on a linear graph to predict the end of life date. The possible effects of oil dilution due to oil maintenance, and/or load variation can mask the true end of life date[3]. Additionally, it is generally accepted that there is a degree of uncertainty in the assessment of the DP values.

It is also recognised that the rates of paper degradation in service-aged transformers are more dependent upon the OEM/design groups[3] rather than years in service which supports the belief there may be a type issue with the Sloy transformers.

This leads to the conclusion that the end of life assessment from straight line analysis of derived DP values must allow a certain amount of tolerance to the actual end of life date. It is possible for end of life to be several years either side of the theoretical date obtained from linear extrapolation. This is especially true for a more rapid end of life calculation when allowing for other conditions on site, not just the polymerisation of papers from normal ageing.

The significance of unplanned transformer failure at this key black start substation must be factored into any decision-making process.

Growth Need

Load profiles for all four GTs for the period of 2013 to 2018 have been downloaded from our PI Historian database. The loading for GT1, GT2 and GT3 has seen a peak of 40MVA across the period, while the loading for GT4 has seen a peak of 33MVA across the period. The reason for the reduced peak on GT4 is the registered capacity of the associated hydro generator connected directly to GT4 is less than the other hydro generators on GT1, GT2 and GT3.

The load profiles show frequent changes in load from minimum loading to peak loading on all four of the GTs. The GTs are subject to these load swings which, although within the continuous maximum rating of the transformers, will exert a thermal impact upon the windings. Any sudden thermal impacts can exacerbate the degrading insulation structure and further weaken the mechanical strength of the insulation.

The Future Energy Scenarios (FES) out to 2050 have shown very limited growth in embedded generation on SHEPDs network at Sloy. Initial discussions with our customer have indicated there is no proposals to upgrade the output capacity of Sloy Power Station. As a result, there is no load driver to install larger capacity transformer units as part of the non-load replacement project.

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[3]INSUCON- 17TH May 2017. Doble presentation “Progress in paper degradation assessment in service-aged transformers”. Presenter Dr Hongzhi Ding.

4 Optioneering

This section presents all the options considered to address the need that is described in Section 3. Each option considered here is either discounted at this Optioneering stage with supporting reasoning provided or is taken forward for detailed analysis in Section 5. Table 1 lists each option and a brief summary.

Table 1 – Option summary table

Option	Option Detail	Taken Forward to Detailed Analysis
Do Nothing Option	Undertake no refurbishment work on the assets.	No
Do Minimum Option	Include additional monitoring on the GTs	No
Refurbishment Option	Undertake offsite refurbishment of the GTs	No
1	In situ replacement of GT3 and GT4 in RIIO T2 period, and replace GT1 and GT2 in the RIIO T3 period.	No
2	Offline build of GT3 and GT4 in RIIO T2 period, and replace GT1 and GT2 in the RIIO T3 period.	Yes
3	Offline Build of GT1, GT2, GT3, and GT4 in RIIO T2 period.	Yes
4	Offline Build of GT1, GT2, GT3, and GT4 and an additional 11kV busbar for additional generator security in RIIO T2 period.	No
5	Offline build of GT3 in RIIO T2 period, and replace GT1, GT2 and GT4 in the RIIO T3 period.	Yes

Do Nothing Option

The Do Nothing option undertakes no refurbishment work on the transformers. This option has been discounted at this stage as the ACR and work undertaken by Polaris do not support a do nothing option, and have demonstrated a clear and unambiguous need to undertake intervention works on the Sloy transformers in the RIIO T2 period to prevent the temporary or permanent loss of these transformers. Without intervention the internal condition of these units is expected to further deteriorate and there is a risk of multiple transformer failure units at Sloy.

NOT PROGRESSED TO DETAILED ANALYSIS

Do Minimum Option

The do minimum option does not undertake any major intervention on the transformers but would include for additional monitoring on the transformers. Additional monitoring and increased oil sampling will not "extend" the life of the GTs at Sloy. The major issue on the transformers is the accelerated ageing of the solid insulation. While additional monitoring offers benefits in terms of tracking the assets to end-of-life it will do nothing to restore the condition of the assets or affect their rate of deterioration.

This option has been discounted at this stage as the ACR and work undertaken by Polaris do not support a do minimum solution, and have demonstrated a clear and unambiguous need to undertake intervention works on the Sloy transformers in the RIIO T2 period to prevent the temporary or permanent loss of these units. Although the assets are considered to be within their working life, the accelerated deterioration of the assets as indicated by the DP trends indicate there is a likely type defect establishing in the transformers, and intervention is required. Black start capability for the local region and Scotland could be impacted from failure of any individual transformer unit.

Also there are currently no commercially available devices for continuously monitoring 2-FAL concentrations in oil. Oil interventions to slow the ageing process can be ruled out based on the recommendation from Polaris not to recondition, reclaim, regenerate or top-up the oil as this will affect the 2-FAL concentrations, which are the primary method of surveillance used to monitor the ageing rate of the paper insulation; this will also mask the underlying ageing profile. The recommendations are clear that intervention is required and additional monitoring is not an intervention.

NOT PROGRESSED TO DETAILED ANALYSIS

Refurbishment Option

The refurbishment option would undertake major intervention on the existing transformers. Without intervention the internal condition of these units is expected to further deteriorate and there is a risk of multiple transformer failure. Ageing of solid insulation is permanent and cannot be reversed without major intervention. The major intervention would require off-site refurbishment of the GTs. This would result in extensive outages, entails a number of risks and offers no guarantee of success. During the extensive outages Black start capability for the local region and Scotland would be placed at significant risk.

Oil interventions to slow the ageing process can be ruled out based on the recommendation from Polaris not to recondition, reclaim, regenerate or top-up the oil as this will affect the 2-FAL concentrations, which are the primary method of surveillance used to monitor the ageing rate of the paper insulation; this will also mask the underlying ageing profile.

This option would not achieve current standards due to space constraints in the existing site, and would leave risks in place as a result of fire separation issues. Also this option does not install 11kV circuit breakers on the LV side of the new transformers so does not resolve the asset separation issues that currently exist at Sloy Power Station.

As a result of these highlighted issues this option is not progressed to detailed analysis.

NOT PROGRESSED TO DETAILED ANALYSIS

Option 1

This option considers;

- In situ replacement of GT3 and GT4 on a like for like basis within the existing substation space.
- Removal of the existing GT3 and GT4 from the existing site.

This option will result in the worst two transformers, from a condition basis, being replaced within the RIIO T2 period. GT1 and GT2 would not be replaced until the RIIO T3 period.

However, this option would not achieve current standards due to space constraints in the existing site, and would leave risks in place as a result of fire separation issues. This option would also require a phased approach to the works requiring re-mobilisation to replace GT1 and GT2 in RIIO T3 price control period, increasing the risk of potential failure on these two transformers. This option does not install 11kV circuit breakers on the LV side of the new transformers so does not resolve the asset separation issues that currently exist at Sloy Power Station. As a result of these highlighted issues this option is not progressed to detailed analysis.

NOT PROGRESSED TO DETAILED ANALYSIS

Option 2

This option considers;

- Construction of a new site compound near the existing substation at Sloy Power Station. An offline build of GT3 and GT4 at the new site, with space provision for future offline build of GT1 and GT2.
- Install two 132kV circuit breakers and four 11kV circuit breakers at the new substation.
- Tower and gantry works are required for connection to the OHL, and 11kV cables will be installed to connect to the power station. Temporary tower diversion works are required to connect to the new site.
- Remove the existing GT3 and GT4 and associated equipment at the existing substation.

This option will result in the worst two transformers, from a condition basis, being replaced within the RIIO T2 period. GT1 and GT2 would not be replaced until the RIIO T3 period.

This option would ensure that we meet current specifications for substations. This option would remove operational constraints that exist at the current site, which is the requirement for a second GT to be taken out of service to allow for maintenance on an adjacent bay. However it would not resolve those issues on the GTs that are not replaced in the RIIO T2 period.

The requirement for a new site is likely to have a negative impact on the landscape as it will be remote to the power station and will be located within the Loch Lomond and Trossachs National Park. Mitigation works will be required to reduce the environmental and visual impact. This option would also require a phased approach to the works requiring re-mobilisation to replace GT1 and GT2 in the RIIO T3 price control period, increasing the risk of potential failure on these two transformers. It would also require additional works for temporary tower diversions due to orientation issues that would be faced at the new site if only GT3 and GT4 were replaced initially.

PROGRESSED TO DETAILED ANALYSIS

Option 3

This option considers;

- Construction of a new site compound near the existing substation at the power station. An offline build of GT1, GT2, GT3 and GT4 at the new site.
- Install four 132kV circuit breakers and eight 11kV circuit breakers at the new substation.
- Tower and gantry works are required for connection to the OHL, and 11kV cables will be installed to connect to the power station.
- Remove the existing GT1, GT2, GT3 and GT4 and associated equipment at the existing substation. These transformers cannot be retained as spares due to condition.

This option would ensure that we meet current specifications for substations. This option would remove operational constraints that exist at the current site, which is the requirement for a second GT to be taken out of service to allow for maintenance on an adjacent bay. It would also remove the requirement for returning to site in the next price control period to undertake further transformer replacement works. This option would also address the existing issues around asset separation at the existing power station. The risks associated with the likely type defect manifesting in the transformers, along with the risk of an increase in the deterioration of the insulation, would be removed by this option. Concerns around masking of the true condition of the insulation due to the effects of oil dilution and load variation would be alleviated. The option would also mitigate the impact on Black Start strategy as a result of the heightened risk of a catastrophic failure of one or more of the existing GTs considering the condition of the GTs, as well as the security to demand customers at the GSP.

The requirement for a new site is likely to have a negative impact on the landscape as it will be remote to the power station and will be located within the Loch Lomond and Trossachs National Park. Mitigation works will be required to reduce the environmental and visual impact.

PROGRESSED TO DETAILED ANALYSIS

Option 4

This option considers;

- Construction of a new site compound near the existing substation at the power station. An offline build of GT1, GT2, GT3 and GT4, and a new 11kV board at the new site.
- Install four 132kV circuit breakers and eight 11kV circuit breakers at the new substation.
- Tower and gantry works are required for connection to the OHL, and 11kV cables will be installed to connect to the power station.
- Remove the existing GT1, GT2, GT3 and GT4 and associated equipment at the existing substation. These transformers cannot be retained as spares due to condition.

This option would ensure that we meet current specifications for substations. This option would remove operational constraints that exist at the current site, which is the requirement for a second GT to be taken out of service to allow for maintenance on an adjacent bay. It would also remove the requirement for returning to site in the next price control period to undertake further transformer replacement works.

The requirement for a new site is likely to have a negative impact on the landscape as it will be remote to the power station and will be located within the Loch Lomond and Trossachs National Park. Mitigation works will be required to reduce the environmental and visual impact.

The 11kV busbar adds additional costs to the project but provides no additional benefit for SHE Transmission or the User. As a result, option 4 is not progressed to detailed to analysis.

NOT PROGRESSED TO DETAILED ANALYSIS

Option 5

This option considers;

- Construction of a new site compound near the existing substation at Sloy Power Station. An offline build GT3 at the new site, with space provision for future offline build of GT1, GT2 and GT4.
- Install one 132kV circuit breakers and two 11kV circuit breakers at the new substation.

- Tower and gantry works are required for connection to the OHL, and 11kV cables will be installed to connect to the power station. Temporary tower diversion works to connect to the new site.

- Remove the existing GT3 and associated equipment at the existing substation.

This option will result in the transformer considered to be most at risk of failure in RIIO T2, GT3, being replaced. GT1, GT2 and GT4 would not be replaced until the RIIO T3 period.

This option would ensure that we meet current specifications for substations. This option would remove operational constraints for GT3 that exist at the current site, which is the requirement for a second GT to be taken out of service to allow for maintenance on an adjacent bay. However it would not resolve those issues on the GTs that are not replaced.

The requirement for a new site is likely to have a negative impact on the landscape as it will be remote to the power station and will be located within the Loch Lomond and Trossachs National Park. Mitigation works will be required to reduce the environmental and visual impact. This option would also require a phased approach to the works requiring re-mobilisation to replace GT1, GT2 and GT4 in the RIIO T3 price control period, increasing the risk of potential failure on these three transformers. It would also require additional works for temporary tower diversions due to orientation issues that would be faced at the new site if only GT3 were replaced initially.

PROGRESSED TO DETAILED ANALYSIS

5 Detailed Analysis

This section considers in more detail each of the options taken forward from the Optioneering section. Where appropriate the results of Cost Benefit Analysis are discussed and together with supporting objective and engineering judgement contribute toward the identification of a selected option. The section continues by setting out the costs for the selected option.

5.1 Cost Benefit Analysis

Option 2, Option 3 and Option 5 have been progressed to detailed analysis and have been included in the Cost Benefit Analysis (CBA). Our CBA Methodology[4] sets the process and mechanics of our approach to CBA. The non-load requirement for the RIIO T2 period is addressed through the baseline option – Option 5. The CBA is being undertaken to help determine the benefits of undertaking the replacement of all four GTs in the T2 period as opposed to only one GT, or two GTs, with the remaining GTs being undertaken in the T3 period. Option 5 is considered the baseline option as it undertakes the replacement of only one GT within the T2 period, which is the least of the options.

In order to assess if there is a benefit of undertaking all four GTs within the T2 period under Option 3, the additional works in the RIIO T3 price control period under Option 2 and Option 5 need to be considered within the option costing. Therefore, the cost profile for the baseline option (Option 5), and Option 2 includes the costs for returning to site in the RIIO T3 price control period to undertake the additional works to replace the remaining transformers. The total forecast expenditure below includes for a consideration of Operational Expenditure costs across the lifetime of the assets.

A counterfactual NPV analysis has been undertaken. The NPV's for each of the three options were calculated, and then the NPVs for Option 2 and Option 5 have been compared against the Baseline Option 5. The output from the CBA is shown in Table 2.

Table 2 – CBA results for the Sloy Substation Works.

CBA Option No.	Total Forecast Expenditure *(£m)*	Total NPV	Delta *(Option to baseline)*	Total NPV *(Incl. Monetised Risk £m)*
[redacted]	[redacted]	[redacted]		[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

The CBA has shown that in the analysis of the three options, Option 3 has the highest comparative NPV against the Baseline Option 5 and Option 2. The difference between the total NPV for Option 3 and the Baseline Option 5 [redacted].

[4] Cost Benefit Analysis Methodology

The long term benefit calculations only considers lead assets and is not developed enough to recognise resilience benefit. Where a lead asset does not currently exist but is added as part of an option, it will produce a “negative benefit” in the calculation. Option 3 has four new 132kV circuit breakers, lead assets, installed in RIIO T2 while the baseline option only has one new 132kV asset in RIIO T2 with the remaining three being installed in RIIO T3. These additional lead assets for the five year period between T2 and T3 leads to the big difference in long term benefit and explains why the baseline option comes out more favourably when including monetised risk.

The NPV results from the CBA show it would more economic to undertake the replacement of all four GTs in the T2 period, as opposed to undertaking the replacement of one or two GTs in T2 and the replacement of the remaining GTs in T3.

In addition to this, engagement on the proposed solutions has been undertaken with a number of stakeholders including local generators and DNO. These stakeholders will be directly impacted by the works and outages required to replace the transformers. We have also engaged with adjacent neighbours and landowners, and statutory licensees such as Transport Scotland. The feedback we have received from stakeholders on the options has indicated a preference for us to consider the “Responsible Operator” approach and undertake the necessary works under one project within T2, rather than having to re-mobilise in the next price control period and return to site to undertake replacement works.

5.2 Project Sensitivity

As outlined in our core RIIO-T2 business plan document, “A Network for Net Zero”, we believe we have a critical role to play in delivering Net Zero ambitions in both the UK and Scotland. Therefore, our plan has been carefully designed with the flexibility to deliver pathways to Net Zero. Our policy paper “A Risk-Based Approach to Asset Management” outlines our approach to monitoring and assessing the condition of our assets to maintain the reliable and resilient network that is expected by our stakeholders. Where asset condition deteriorates, we undertake a programme of cost-effective, risk-based interventions to maintain the longevity and performance of the transmission network. Each of our non-load related projects for T2 is underpinned by Asset Condition Reports which clearly outline that the works are necessary and driven by reliability.

Table 3 – Sensitivity Analysis Table

Sensitivity	Test and impact observed – switching inputs
Asset Performance / deterioration rates	Switching deterioration assumption: The asset performance / deterioration rates can only improve or deteriorate. As the need for this project is driven by an asset condition report (as outlined in Section 3), the asset condition will not improve in the intervening period. The second option is for the asset performance to deteriorate and therefore the need remains, and the project would be considered for advancement within available outages.
Ongoing efficiency assumptions	Switching efficiency assumption: increased or decreased. Test would have no impact on (feasible) option selection, as the options move in parallel and have no impact on ordering within CBA.
Demand variations	No significant demand forecast.
Energy scenarios	Sensitivity considered in Section 3 (Need) already. As this is a non-load project and the need is driven by the asset condition, the work would be required regardless of any changes to the energy scenarios.
Asset utilisation	Our policy paper "A Risk-Based Approach to Asset Management" outlines our approach to monitoring and assessing the condition of our assets to maintain the reliable and resilient network that is expected by our stakeholders. Where asset condition deteriorates, we undertake a programme of cost-effective, risk-based interventions to maintain the longevity and performance of the transmission network. Each of our non-load related projects for T2 is underpinned by Asset Condition Reports which clearly outline that the works are necessary and driven for reliability.
Timing / delivery	We have considered timing of investments as part of our CBAs.
Consenting / stakeholders	Where applicable we have considered consenting and stakeholder engagement as part of section 5 (Detailed Analysis) and the impact which this has had on the selection of the preferred solution.
Public policy / Government legislation	We have considered the impact of public policy, government legislation and regulations as part of the need (Section 3), optioneering (Section 4) and detailed analysis (Section 5) and the impacts this has on the selection of the preferred solution. For example, the projects have considered the impact of the UK Governments' Net Zero emission by 2050 target, SQSS and ESQCR.

5.3 Proposed Solution

Based on the output of the CBA, and considering the stakeholder feedback on the options, the proposed solution is Option 3 as detailed in Section 4 Optioneering of this justification report. This option is the offline replacement at a new site of all four GTs at Sloy substation. This meets the requirements of the asset condition-based replacement that has to be undertaken within T2. It avoids us having to undertake additional spend for temporary tower diversions that would be required if undertaking an offline rebuild of GT3 only in T2 (Option 5), or GT3 and GT4 only in T2 (Option 2), due to orientation issues that would be faced at the new site. This option addresses the risks associated with the accelerating ageing of the solid insulation seen across all four GTs at Sloy, and the type defect that is manifesting on these units. Concerns around masking of the true condition of the insulation due to the effects of oil dilution and load variation would be alleviated. The option would also mitigate the impact on Black Start strategy as a result of the heightened risk of a catastrophic failure of one or more of the existing GTs considering the condition of the GTs, as well as the security to demand customers at the GSP. It also removes the requirement to re-mobilise in the next price control period to undertake further asset condition-based replacements. This meets stakeholder preferences for us to undertake the works as part of one project.

Table 4 – Outputs from Proposed Solution

Plant	Size of new plant	Replacement for
132/11kV transformer and ancillary plant	4 x 30/60MVA 132/11kV transformers	4 x 25/50MVA 132/11kV transformers
132kV switchgear	4 x 132kV circuit breakers	-
11kV switchgear	4 x 11kV circuit breaker	-

Competition

5.4 Competition

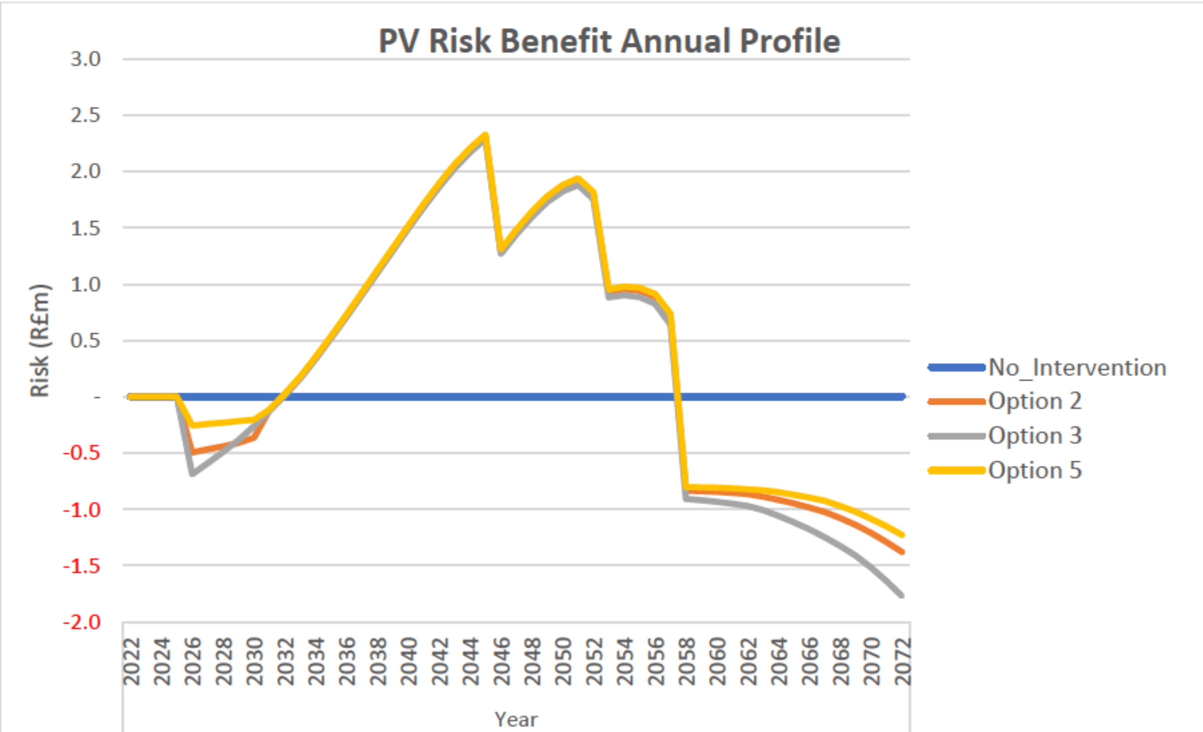
The Sloy Substation Works project is not flagged as eligible for early or late competition due to it being under Ofgem's £50m and £100m thresholds respectively.

5.5 Risk Benefit

A Risk Benefit Analysis has been carried out in order to compare "no intervention" against the selected "with intervention" option. Please note that while monetised risk is denoted as a financial figure, it is important to note that it is not "real" money and does not correspond to the cost that SHE Transmission would incur if an asset was to fail and these values are thus identified with R£ prefix (for more details please refer to A Risk Based Approach to Asset Management[1]).

The long-term monetised risk benefit which would be realised through the completion of this project is R[redacted]. The long-term benefit is derived by consideration of the risk of the asset experiencing a catastrophic failure weighted by the probability that the asset will survive for the Options and "no intervention" scenarios. The long-term benefit is an aggregation of the risk of all assets being considered within the option. The risk of each Option is then compared with the "no intervention" scenario. The "no intervention" scenario assumes that when the asset experiences a catastrophic failure the asset is replaced.

Figure 3. Long Term Benefit of Proposed Intervention – Option 3: 4 Transformer Rebuild



In addition to assessing the long-term risk benefit, a monetised risk benefit has also been determined. The monetised risk benefit which would be realised through the completion of this project is [redacted]. The immediate increase in monetised risk is as a result of introducing new lead assets (circuit breakers) where none previously existed, which introduce an increased risk profile.

Due to current functionality, the model only tracks one intervention performed in the year 2026 and tracks its long-term risk benefit until 2072. This intervention may only have a certain expected shelf life before further interventions should be used to maintain a certain level of risk on the asset. As the current model can only render one of these interventions, it's monetised risk benefit over time will begin to decrease depending on predicted asset failure curves. This may eventually lead to negative risk benefits (Per Year) found in later life or in the worst case an overall Negative Long-Term Risk Benefit between the years 2026 to 2072.

5.6 Innovation & Sustainability

This substation will be situated in an environmentally sensitive area. Therefore, we will consider the use of ester-based fluid filled transformer units in the design to mitigate the potential environmental impact of the installation.

5.7 Carbon Modelling

We are committed to managing resources over the whole asset lifecycle – i.e. including the manufacturing of assets, construction, operations and decommissioning activities – to reduce our greenhouse gas emissions in line with climate science and become a climate resilient business. It is our aspiration that the carbon lifecycle cost of investment options plays a key role within our project development and is considered in the selection of a preferred solution. We have therefore developed an internal carbon pricing model that estimates a carbon cost for each option considered in our CBA through deriving values for:

1. Embodied carbon, which relates to the carbon emissions associated with the manufacturing and production of the materials use in production of the lead assets (transformer, reactors, underground cables and overhead lines. Overhead line is made up of tower/wood pole/composite pole, conductor and fittings) procured and installed as part of the project.

2. The carbon emissions associated with the main stages of the project lifecycle (construction, operations and decommissioning).

It is our vision to embed carbon considerations within our strategic optioneering and project development processes, which will require us to determine a way of flagging high carbon options within our CBA outputs. We will continue to develop our thinking in this space, which will involve our model being validated by a third party, so the results included in this EJP are indicative and subject to change.

In terms of the results of analysis for this project, which are captured in the carbon footprint results table, the carbon footprint modelling for the preferred Option 3 is included in Table 5. We are still developing our carbon modelling, and through this we hope to be able to identify methods to reduce the carbon impact as the project moves through the development process.

Table 5 – Carbon Footprint Modelling for the preferred Sloy Substation Option.

	Project Information	Option 3
Project info	Project Name/number	
	Construction Start Year	2026
	Construction End Year	2028
Cost estimate £GBP	Embodied carbon	£ 284,532
	Construction	£ 436,025
	Operations	£ 78,408
	Decommissioning	£ 199,624
	Total Project Carbon Cost Estimate	**£ 998,589**
Carbon footprint tCO2e	Embodied carbon	3,799
	Construction	5,735
	Operations	343
	Decommissioning	574
	Total Project Carbon (tCO2e)	**10,451**
Project Carbon Footprint by Emission Category	Total Scope 1 (tCO2e)	172
	Total Scope 2 (tCO2e)	171
	Total Scope 3 (tCO2e)	10,108
SF_6 Emissions	Total SF_6 Emissions 3 (tCO2e)	137

5.8 Cost Estimate

The cost of the preferred option for works at Sloy has been developed using rates from existing substation framework contracts and benchmarks from delivered RIIO-T1 projects. The total cost for delivering the scope of works for the proposed solution is £45.3m. The works are planned to be completed within the RIIO T2 period.

6 Conclusion

This paper identifies the need for intervention on the transformers at Sloy. The primary driver for this scheme is the asset condition of the existing transformers.

Following Ofgem's published Draft Determination in July, we have re-assessed the need in conjunction with an independent consultant, and the options for this project. The proposed option has not changed as a result of this review.

Following optioneering and detailed analysis, as set out in this paper, the proposed scope of works is:

- Construction of a new site compound near the existing substation at the power station. An offline build of GT1, GT2, GT3 and GT4 at the new site.
- At the new substation install four 132kV circuit breakers, and eight 11kV circuit breakers.
- The existing GT1, GT2, GT3 and GT4 and associated equipment at the existing substation are to be removed.
- Tower and gantry works are required for connection to the OHL, and 11kV cables will be installed to connect to the power station.

This scheme will cost [redacted] and will deliver the following outputs and benefits during the RIIO-T2 period:

- A long-term monetised risk benefit of [redacted];
- An immediate reduction of network risk calculated [redacted]; see Section 5 for details; and,
- Improved operational flexibility and resilience in line with our goal to aim for 100% transmission network reliability for homes and businesses.

The Sloy Substation Works project is not flagged as eligible for early or late competition due to it being under Ofgem's £50m and £100m thresholds respectively.

7 Price Control Deliverables and Ring Fencing

As set out in our Regulatory Framework paper (Section 1.12 and Appendix 3) we support a key principle from Citizens Advice – one that guarantees delivery of outcomes equivalent to the funding received - to ensure that RIIO-T2 really deliver for consumers.

For our core non-load projects this means that we commit to delivering our overarching NARMs target. If we do not deliver the NARMS target, or a materially equivalent target, then we should be subject to a penalty. Equally, if we over-deliver against our target and are able to justify that the over-delivery is in the consumers interests and could not have been reasonably factored into our business plan at the time of target setting then we should be made cost neutral for this work.

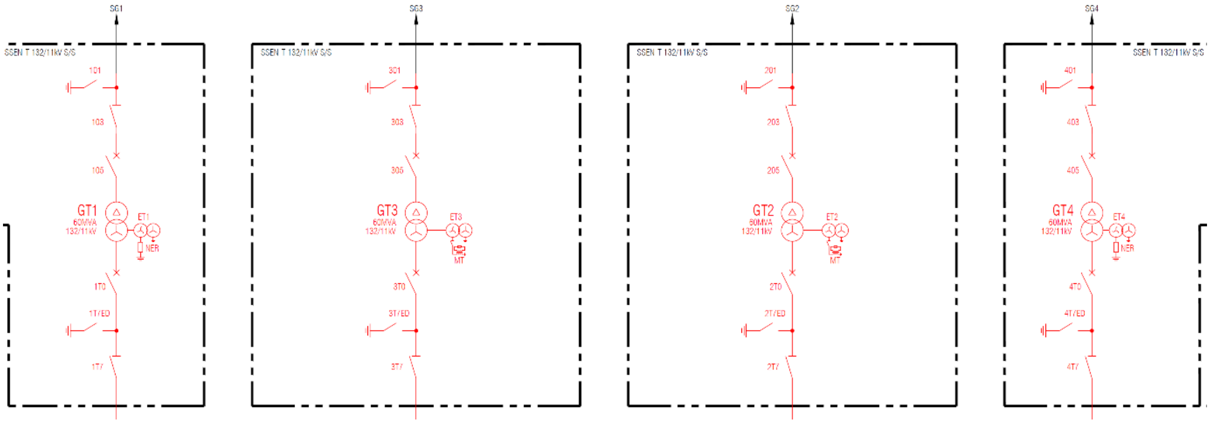
Core non load projects should not be ring fenced. This is to allow for substitution of projects in order to meet that NARMs target. We need flexibility to respond to up to date asset data information or external influences on our network during the price control; this information might drive us to substitute one project for another in order to ensure a reliable and resilient network. Ring fencing projects may result in sub-optimal decisions, having adverse consequences for the health of our network, which will ultimately be reflected in the NARMs target.

8 Outputs included in RIIO T1 Business Plan

There are no outputs associated with this scheme included in our RIIO T1 plans.

Appendices

Appendix A: New Proposed Sloy Substation Electrical diagram



Appendix B: Polaris Condition Assessment Summary Reports

Polaris Summary Report GT1

Polaris Summary Report GT2

Polaris Diagnostics & Engineering Ltd

Polaris Diagnostics & Engineering Ltd has been commissioned by Scottish Hydro Electric Transmission (SHE Transmission), to carry out a Level 1 condition assessment of Sloy GT2 132/11kV Transformer.

The level 1 condition assessment has been carried out, based on a review and independent assessment of the historic oil data and SSEN Report T2BP-ACR-0011 Revision 1.10 dated October 2019,both supplied by SHE Transmission.

Based on the assessment of the historical & current asset condition data, there is a high likelihood that the transformer condition will deteriorate during the RIIO T2 period, resulting in a possible failure of the asset. The transformer should be kept under surveillance pending further investigation of the suspected type defect.

This is evidenced by the increase in main tank 2FAL concentrations within the transformer main tank Measured 2FAL of 0.18 gives an estimated DP of 641. The insulation within a new transformer has typically a DP value of 1000. It is generally accepted within the industry that an estimated DP value of 200 is “end of life”. Application of this criteria, results in the transformer having an estimated 55% residual life remaining in the paper insulation. This suggests that the paper insulation is currently in reasonable condition but is exhibiting evidence of ageing by the increasing 2FAL concentrations. Based on the overall rate of ageing, and assuming that there is no deviation in that rate, or that the transformer is not subjected to external failure mechanism, would predict that “end of life” would be reached beyond the RIIO T2 period. However, as the main tank oil was diluted or subjected to change in load flow in 2014, as evidenced by the reduction in 2FAL and the corresponding apparent increase in estimated DP, it is considered that the true “end of life” will be reached more prematurely than originally estimated.

It is known that a number of short circuits have occurred on the 11kV busbars at Sloy substation since they were installed in the 1990s. A through fault current could cause winding movement or winding clamp distortion due to electromechanical forces generated by the through fault, which would seriously compromise the through fault withstand capability of the transformer. Ageing of paper insulation would also cause winding shrinkage, which would also contribute to a reduction in the through fault withstand of the transformer, increasing the risk of instantaneous failure due to a fault on the 11kV busbars.

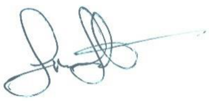
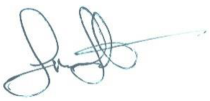
It is likely that there is a type defect manifesting in this transformer, as characterised by accelerated ageing of the paper insulation, which is detected by increasing levels of 2FAL in all 132/11kV transformers at Sloy substation. The root cause of this has not yet been determined and will require further investigation. In order to further assess the condition of this transformer, to establish the root cause of the accelerated ageing and manage the asset to end of life, the following recommendations are made:

- Main tank oil should be sampled at 6 monthly intervals, in order to keep the levels of 2FAL under surveillance and to assess the ageing rate. This is in addition to routine sampling. On line monitoring of 2FAL is not presently an option as the technology is not mature.

- Electrical diagnostic testing. This is to assess the mechanical condition of the active part by Sweep Frequency Response Analysis (SFRA) and the condition of the insulation system by means of dielectric frequency response (DFR), 10kV Power Factor and 5kV Insulation Resistance. This will require an outage and the disconnection and removal of the 132kV & 11kV busbars.

The main tank oil should not be reconditioned, reclaimed, regenerated or topped up as this will affect the 2FAL concentrations, which is the primary method of surveillance used to monitor the ageing rate of the paper insulation. These interventions will mask any underlying ageing profile. This of course should be reviewed, by Transmission Operations in the case where the dielectric properties of the main tank oil are deteriorating and presenting a risk of dielectric failure of the liquid insulation.

In order to establish the root cause of the accelerated ageing an “end of life” evaluation should be carried out on this transformer, at the time when it’s to be removed from the system. This should comprise of on-site testing and inspection, forensic examination during dismantling at the scrap yard and DP analysis of paper insulation retrieved from the windings during dismantling. Any recommendations derived from the “end of life” evaluation should be used to manage operational transformers of similar design.

Author	Issue Authority
Ian B B Hunter Technical Director	Ian B B Hunter Technical Director
	

Polaris Summary Report GT3

Polaris Diagnostics & Engineering Ltd

Polaris Diagnostics & Engineering Ltd has been commissioned by Scottish Hydro Electric Transmission (SHE Transmission), to carry out a Level 1 condition assessment of Sloy GT3 132/11kV Transformer.

The level 1 condition assessment has been carried out, based on a review and independent assessment of the historic oil data and SSEN Report T2BP-ACR-0011 Revision 1.10 dated October 2019,both supplied by SHE Transmission.

Based on the assessment of the historical & current asset condition data, there is a high likelihood that the transformer condition will deteriorate during the RIIO T2 period, resulting in failure of the asset. The transformer should be planned for replacement.

Measured 2FAL of 1.14 gives an estimated DP of 412. The insulation within a new transformer has typically a DP value of 1000. It is generally accepted within the industry that an estimated DP value of 200 is "end of life". Application of this criteria, results in the transformer having an estimated 26% residual life remaining in the paper insulation. This is consistent with the paper insulation being in an aged condition. Between 2007 and 2014 there is an almost linear and sustained ageing rate, which is considered to be genuine. A reduction in load flow or oil intervention (either oil top up or oil processing) in 2014 has diluted the 2FAL in such a way as to manifest as an apparent increase in estimated DP which camouflages the true estimated DP in 2019, which will be in a worse condition than predicted. Extrapolation of the estimated DP between 2007 and 2014, based on the observable rate of ageing, and assuming that there is no deviation in that rate, or that the transformer is not subjected to external failure mechanism, would predict that "end of life" would be reached in the year 2026. The transformer has 6 years of operational service life remaining, which is within the RIIO T2 period.

It is known that a number of short circuits have occurred on the 11kV busbars at Sloy substation since they were installed in the 1990s. A through fault current could cause winding movement or winding clamp distortion due to electromechanical forces generated by the through fault, which would seriously compromise the through fault withstand capability of the transformer. Ageing of paper insulation would also cause winding shrinkage, which would also contribute to a reduction in the through fault withstand of the transformer, increasing the risk of instantaneous failure due to a fault on the 11kV busbars.

It is likely that there is a type defect manifesting in this transformer, as characterised by accelerated ageing of the paper insulation, which is detected by increasing levels of 2FAL in all 132/11kV transformers at Sloy substation. The root cause of this has not yet been determined and will require further investigation. In order to further assess the condition of this transformer, to establish the root cause of the accelerated ageing and manage the asset to end of life, the following recommendations are made:

- Main tank oil should be sampled at 6 monthly intervals, in order to keep the levels of 2FAL under surveillance and to assess the ageing rate. This is in addition to routine sampling. On line monitoring of 2FAL is not presently an option as the technology is not mature.

- Electrical diagnostic testing. This is to assess the mechanical condition of the active part by Sweep Frequency Response Analysis (SFRA) and the condition of the insulation system by means of dielectric frequency response (DFR), 10kV Power Factor and 5kV Insulation Resistance. This will require an outage and the disconnection and removal of the 132kV & 11kV busbars.

The main tank oil should not be reconditioned, reclaimed, regenerated or topped up as this will affect the 2FAL concentrations, which is the primary method of surveillance used to monitor the ageing rate of the paper insulation. These interventions will mask any underlying ageing profile. This of course should be reviewed, by Transmission Operations in the case where the dielectric properties of the main tank oil is deteriorating and presenting a risk of dielectric failure of the liquid insulation.

In order to establish the root cause of the accelerated ageing an “end of life” evaluation should be carried out on this transformer, at the time when it’s to be removed from the system. This should comprise of on-site testing and inspection, forensic examination during dismantling at the scrap yard and DP analysis of paper insulation retrieved from the windings during dismantling. Any recommendations derived from the “end of life” evaluation should be used to manage operational transformers of similar design.

Author	**Issue Authority**
Ian B B Hunter Technical Director	Ian B B Hunter Technical Director

Polaris Summary Report GT4

Polaris Diagnostics & Engineering Ltd

Polaris Diagnostics & Engineering Ltd has been commissioned by Scottish Hydro Electric Transmission (SHE Transmission), to carry out a Level 1 condition assessment of Sloy GT4 132/11kV Transformer.

The level 1 condition assessment has been carried out, based on a review and independent assessment of the historic oil data and SSEN Report T2BP-ACR-0011 Revision 1.10 dated October 2019,both supplied by SHE Transmission.

Based on the assessment of the historical & current asset condition data, there is a high likelihood that the transformer condition will deteriorate during the RIIO T2 period, resulting in a possible failure of the asset. The transformer should be kept under surveillance pending further investigation of the suspected type defect.

This is evidenced by the increase in main tank 2FAL concentrations within the transformer main tank. Measured 2FAL of 0.22 gives an estimated DP of 616. The insulation within a new transformer has typically a DP value of 1000. It is generally accepted within the industry that an estimated DP value of 200 is “end of life”. Application of this criteria, results in the transformer having an estimated 52% residual life remaining in the paper insulation. This suggests that the paper insulation is currently in reasonable condition but is exhibiting evidence of ageing by the increasing 2FAL concentrations. Based on the overall rate of ageing, and assuming that there is no deviation in that rate, or that the transformer is not subjected to external failure mechanism, would predict that “end of life” would be reached in the year 2030, and has 10 years of operational service life remaining, which is beyond the RIIO T2 period.

It is known that a number of short circuits have occurred on the 11kV busbars at Sloy substation since they were installed in the 1990s. A through fault current could cause winding movement or winding clamp distortion due to electromechanical forces generated by the through fault, which would seriously compromise the through fault withstand capability of the transformer. Ageing of paper insulation would also cause winding shrinkage, which would also contribute to a reduction in the through fault withstand of the transformer, increasing the risk of instantaneous failure due to a fault on the 11kV busbars.

It is likely that there is a type defect manifesting in this transformer, as characterised by accelerated ageing of the paper insulation, which is detected by increasing levels of 2FAL in all 132/11kV transformers at Sloy substation. The root cause of this has not yet been determined and will require further investigation.In order to further assess the condition of this transformer, to establish the root cause of the accelerated ageing and manage the asset to end of life, the following recommendations are made:

- Main tank oil should be sampled at 6 monthly intervals, in order to keep the levels of 2FAL under surveillance and to assess the ageing rate. This is in addition to routine sampling. On line monitoring of 2FAL is not presently an option as the technology is not mature.

- Electrical diagnostic testing. This is to assess the mechanical condition of the active part by Sweep Frequency Response Analysis (SFRA) and the condition of the insulation system by means of dielectric frequency response (DFR), 10kV Power Factor and 5kV Insulation Resistance. This will require an outage and the disconnection and removal of the 132kV & 11kV busbars.

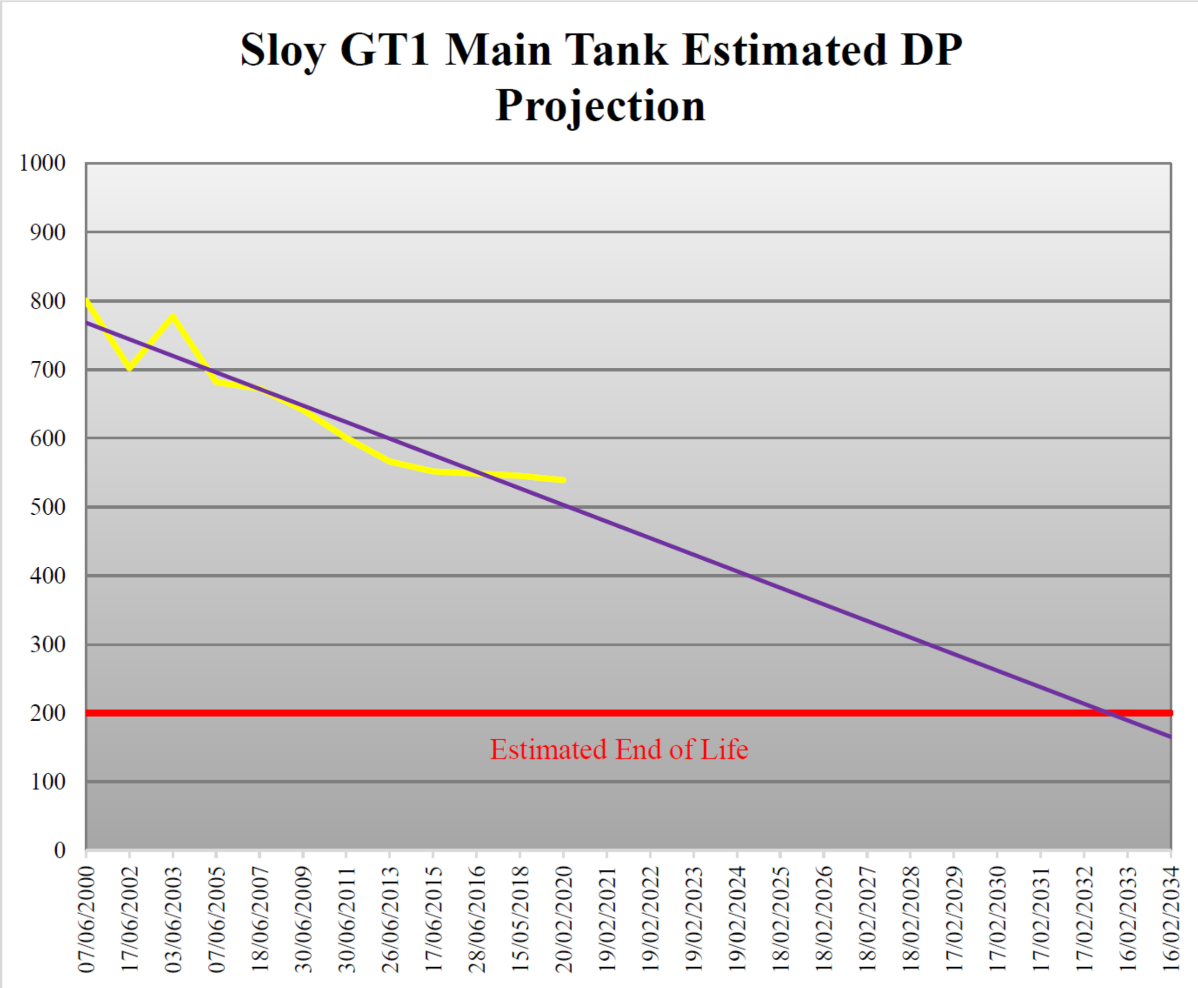
The main tank oil should not be reconditioned, reclaimed, regenerated or topped up as this will affect the 2FAL concentrations, which is the primary method of surveillance used to monitor the ageing rate of the paper insulation. These interventions will mask any underlying ageing profile. This of course should be reviewed, by Transmission Operations in the case where the dielectric properties of the main tank oil are deteriorating and presenting a risk of dielectric failure of the liquid insulation.

In order to establish the root cause of the accelerated ageing an "end of life" evaluation should be carried out on this transformer, at the time when it's to be removed from the system. This should comprise of on-site testing and inspection, forensic examination during dismantling at the scrap yard and DP analysis of paper insulation retrieved from the windings during dismantling. Any recommendations derived from the "end of life" evaluation should be used to manage operational transformers of similar design.

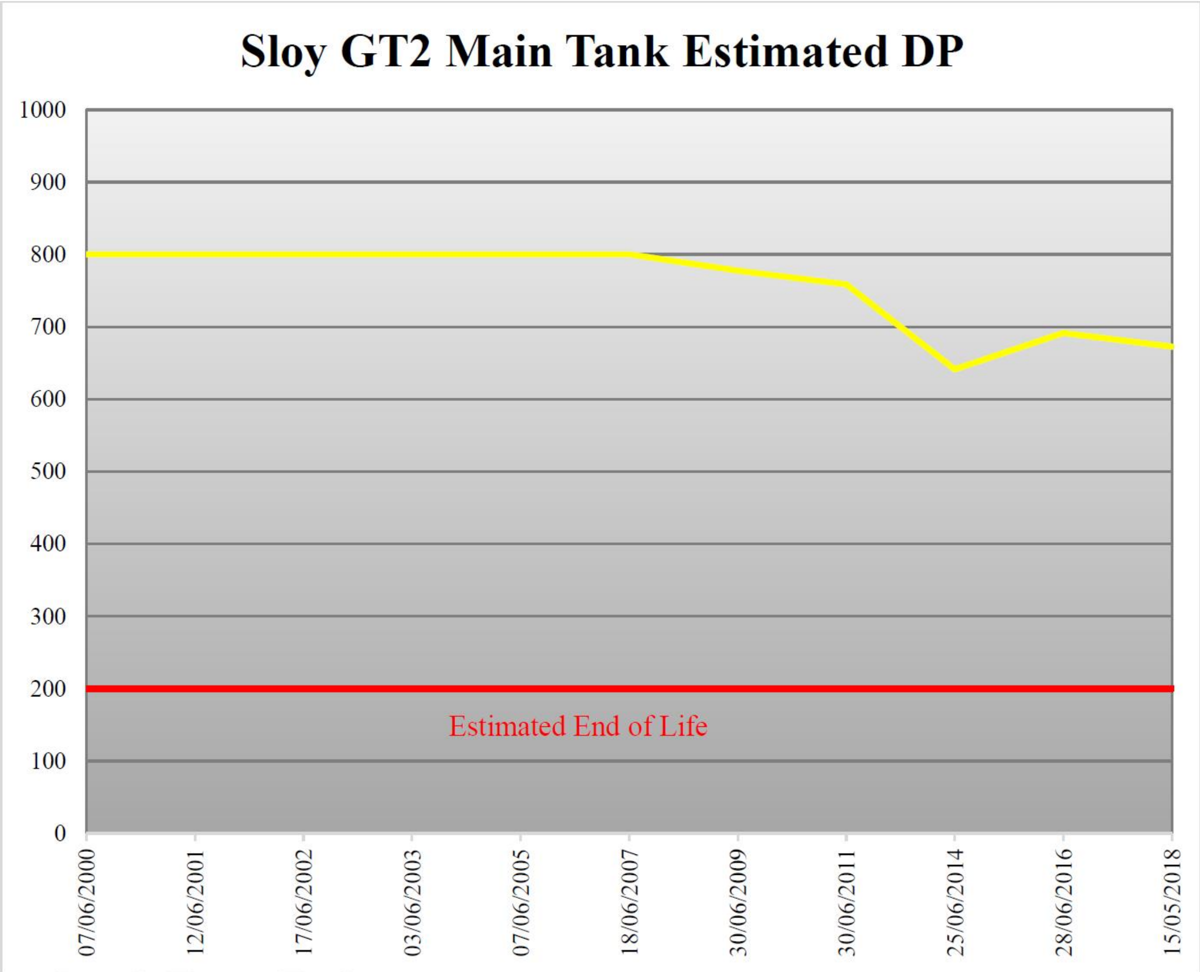
Author	Issue Authority
Ian B B Hunter Technical Director	Ian B B Hunter Technical Director

Appendix C: DP Trend Graphs

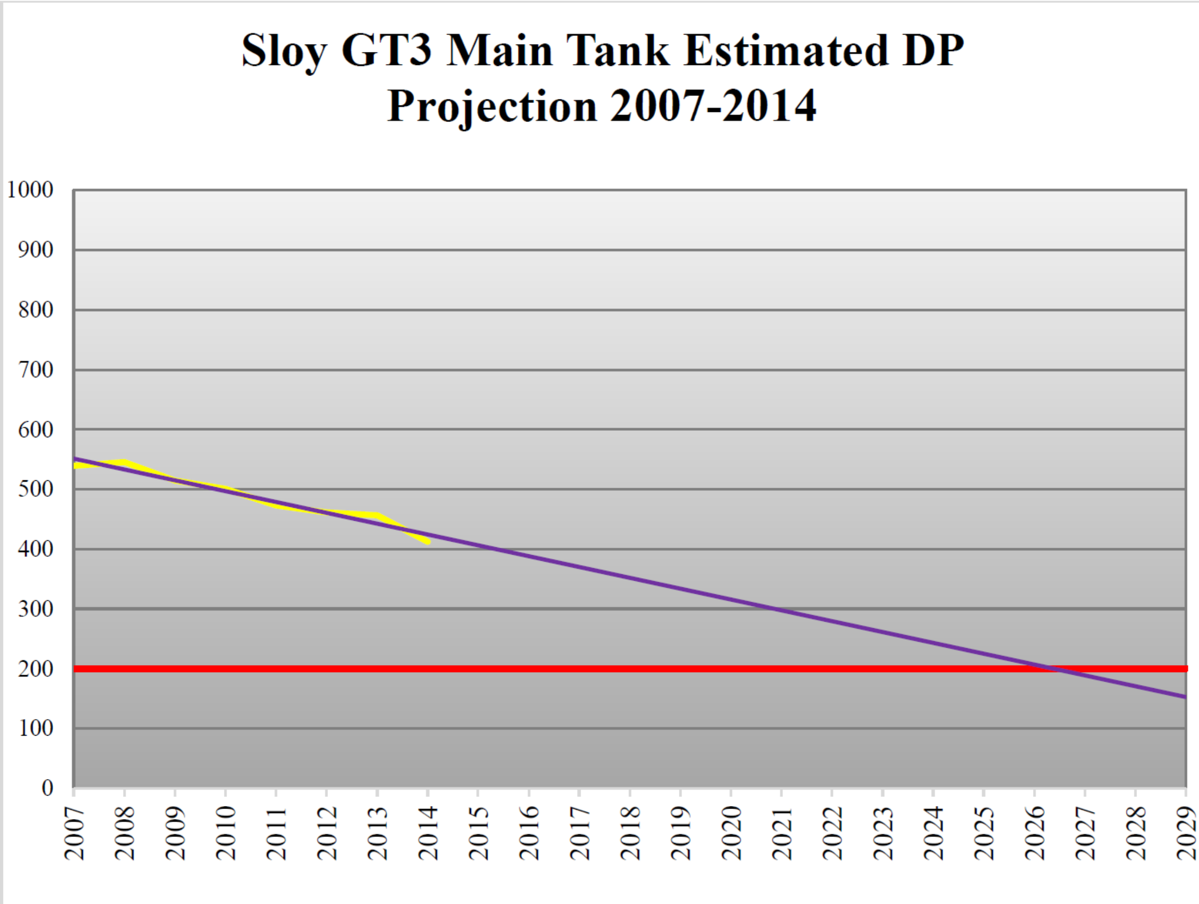
Sloy GT1 DP Trend Graph



Sloy GT2 DP Trend Graph



Sloy GT3 DP Trend Graph



Sloy GT4 DP Trend Graph