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# **Sloy GT4 132/11kV Transformer**

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**Level 1 Condition  
Assessment Report  
15th July 2020  
Report:  
SLOYGT4SHET200626  
FINAL**

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**Ian B B Hunter**

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## Executive Summary

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 SSSEN 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 RIIIO 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 RIIIO 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.



## Issue Record

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Issue Date	Issue No	Author	Amendments
26 <sup>th</sup> June 2020	DRAFT	MJ Gilfeather	-
9 <sup>th</sup> July 2020	DRAFT v2	MJ Gilfeather	Editorials & Clarifications
15 <sup>th</sup> July 2020	FINAL	IBB Hunter	Editorials & Alteration of Report Number

## Issue Authority

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

## Review

This document is subject to review.

This document is issued for the party which commissioned it and for specific purposes connected with the above-captioned project only. It should not be relied upon by any other party or used for any other purpose.

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## Condition Assessment Level

A level 1 condition assessment was carried out on Sloy GT4 132/11kV transformer as defined in the table below.

TRANSFORMER CONDITION ASSESSMENT				
LEVEL	DESCRIPTION*	SITE VISIT REQUIRED	OUTAGE REQUIRED	ASSESSMENT CLASS
<b>Level 1</b>	Oil Data and History Provided by Client for Analysis	No	No	Basic
<b>Level 2</b>	Level 1 & Ground Based Visual Survey	Yes	No	Advanced Basic
<b>Level 3</b>	Level 2 & Non-invasive Surveillance (Thermal Survey/RFI Scan of Transformer)	Yes	No	Intermediate
<b>Level 4</b>	Level 3 & Independent Oil Sampling and Analysis in Accordance with IEC 60422	Yes	No	Advanced
<b>Level 5</b>	Level 4 & Overall Visual Survey	Yes	1 day outage	Detailed
<b>Level 6</b>	Level 5 & Electrical Diagnostic Testing (Ranging from Ratio/mag Current, Winding Resistance, Sweep Frequency Response Analysis, Power Factor and Capacitance, Polarisation Index, Bushing Oil Sampling, Bushing Power Factor and Capacitance)	Yes	1-3 days outage	Comprehensive

\* Condition assessment can be customised to meet individual client requirements.

## Transformer Serial 44653

This transformer was manufactured in 1998, and was installed and commissioned at Sloy 132kV substation.

Sloy GT4 transformer is installed within an outdoor 132kV air insulated substation (AIS) and is fitted with both 132kV and 11kV oil to air bushings and an off circuit tap changer. The transformer is furnished with a separate cooler bank which is free breathing, utilising a refrigerated breather system as a means of moisture management.

### Electrical Plant Details

<b>Manufacturer:</b>	Peebles Power Transformers
<b>Serial Number:</b>	44653 (Serial No obtained from oil analysis report)
<b>Year of Manufacture:</b>	1998
<b>ON/OFB Rating:</b>	25/50 MVA
<b>Ratio:</b>	132/11 kV
<b>Vector Group:</b>	Unknown
<b>Impedance:</b>	Unknown
<b>Tap Changer Manufacturer:</b>	ATL
<b>Tap changer Type:</b>	307/500 A250 LSP
<b>Tap Changer Serial Number:</b>	Unknown
<b>HV Bushings:</b>	Unknown
<b>Oil Type:</b>	Uninhibited, unknown type
<b>Breather Type:</b>	Free Breathing
<b>Moisture Management:</b>	Refrigeration type

## **Oil Quantities & Weights**

Unknown

## **Transformer Construction**

No transformer construction information was made available.

## **Transformer Defects**

Polaris Diagnostics & Engineering Ltd are not aware of any known defects associated with the design of this transformer.



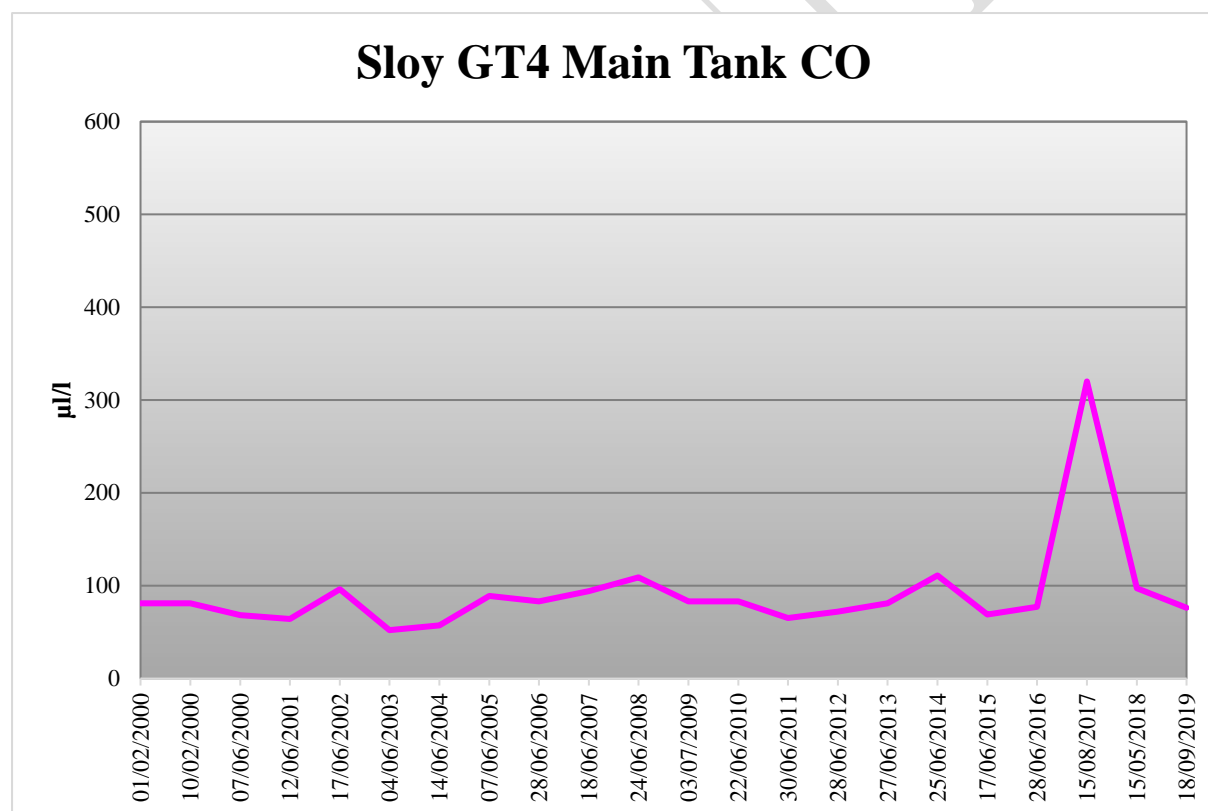
## Main Tank Oil History

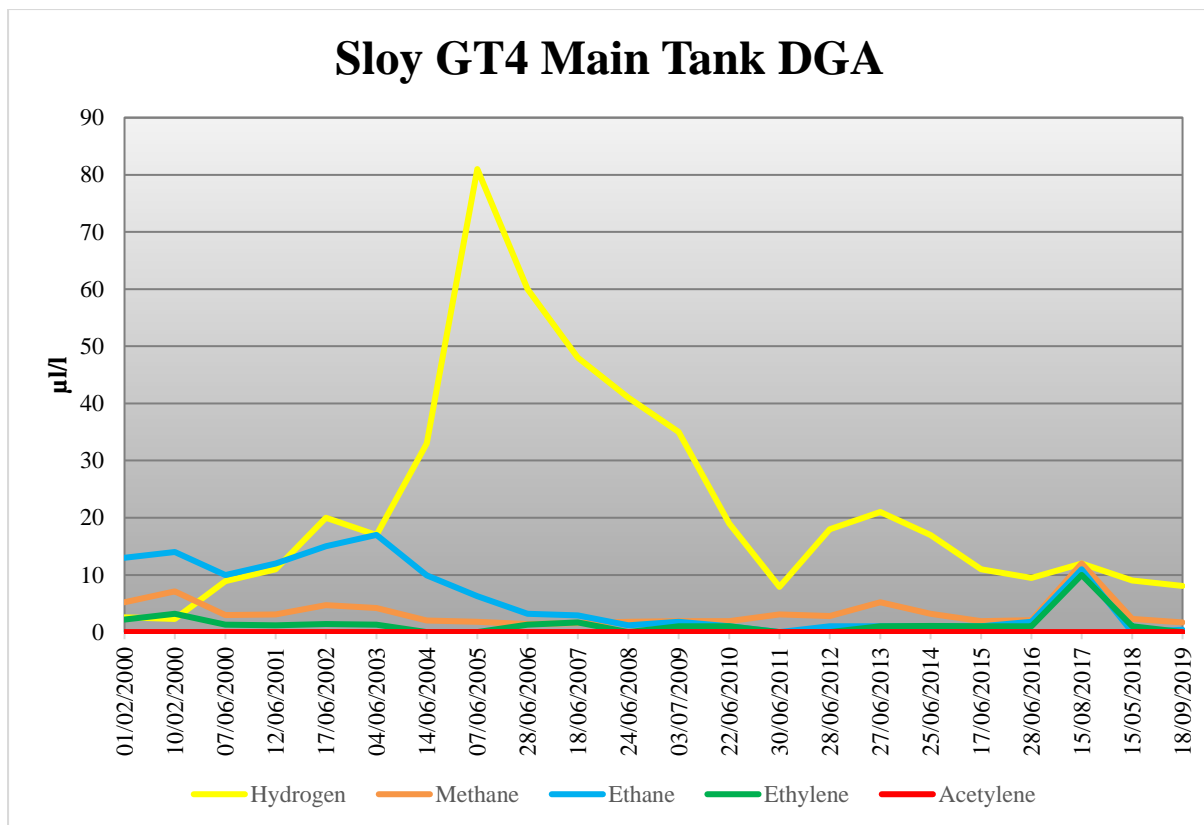
### Dissolved Gas Analysis – Main Tank History

Interpretation of the DGA history is carried out using guidance from IEC 60599 “*Mineral Oil Impregnated Electrical Equipment in Service – Guide to the interpretation of dissolved and free gases analysis*”. The available history spans from 2000 to 2019.

As the values of dissolved Carbon Monoxide (CO) are several orders of magnitude greater than all other diagnostic gases, the CO history is plotted separately for clarity.

The CO characteristic is, overall, relatively stable over the sample period. One spike in generated CO is present in August 2017 which is indicative of a period where there is accelerated ageing of the cellulose insulation. This spike in CO also represents the peak value over the sample period of 320 $\mu$ l/l. CO remains well below “typical values” specified in IEC 60599 over the sample period.





Hydrogen, Methane, Ethane and Ethylene are all present throughout the historical DGA sample range. The dissolved diagnostic gas values measured in the final sample are all below the “typical concentration values” stated within IEC 60599.

Application of the gas ratios, as defined in IEC 60599,  $[0, 0.25, 0]$  fails to highlight any abnormality through a diagnosis of non-classification diagnosis. Using the Duval’s triangle method of DGA interpretation, the same gas ratios define a “PD” condition, “Corona partial discharges”, however, it should be noted that the Duval method being a closed system will always result in a condition being diagnosed. The magnitudes of dissolved gas levels are considered to be too low to accurately diagnose and in this case the DGA would be considered benign.

The DGA does not exhibit any evidence of partial discharge, discharge, or thermal abnormality. The DGA history can be described as benign.

Thermal Events:

None

Discharge Events:

None

## Main Tank Oil Quality Analysis

Interpretation of the oil analysis is carried out in accordance with the requirements of IEC 60422 *“Mineral insulating oils in electrical equipment – supervision and maintenance guidance.”* As this transformer has a primary voltage of 132kV, it falls into the “Category B” limits as defined in the standard.

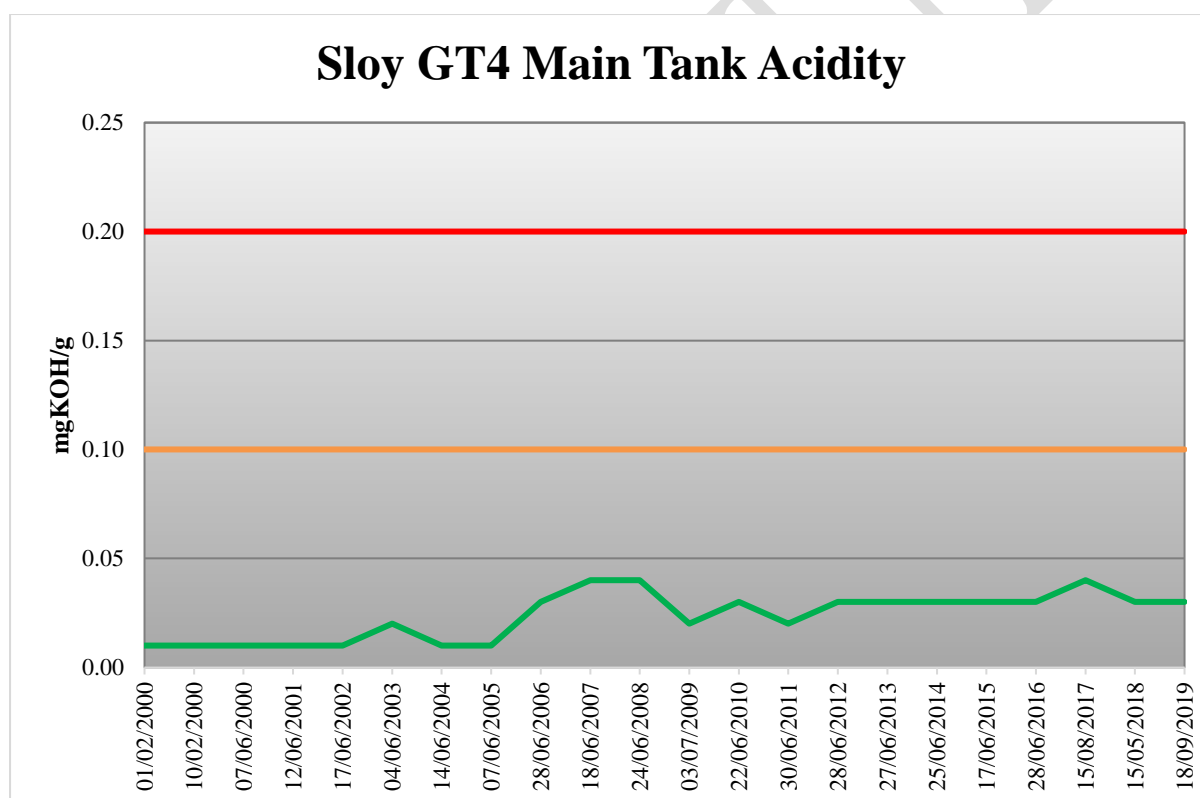
The main tank oil was tested for corrosive sulphur in august 2011, the results of which were found to be potentially corrosive.

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## Acidity

The acidity of used oil is due to the formation of acidic oxidation products. Acids and other oxidation products will in conjunction with water and solid contaminants affect the dielectric and other properties of the oil. Acids have an impact on the degradation of cellulosic materials and maybe responsible for the corrosion of metal parts in a transformer.

IEC 60422 “Category B” Limits for Acidity	
Classification	mgKOH/g
Good	< 0.1
Fair	0.1 – 0.2
Poor	> 0.2

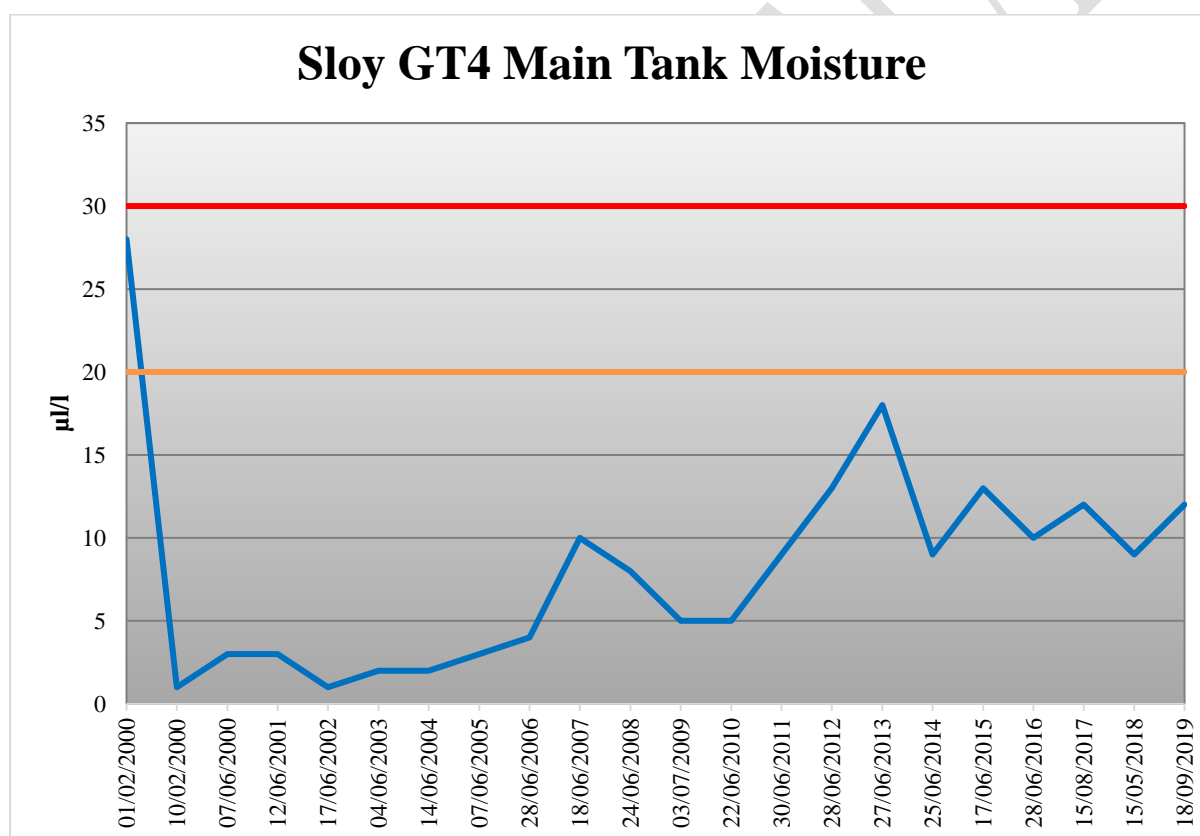


The historical acidity record has 22 samples taken in the period of 2000 to 2019. The acidity levels are found to exhibit a very minor increasing trend over the sample period. Over the entire historical sample range all results can be categorised as “Good” as defined by IEC 60422 for category B apparatus. The acidity is considered satisfactory.

## Moisture

The moisture level influences the breakdown voltage of the oil, the solid insulation and affects the ageing characteristics of the liquid and solid insulation. There are two main sources of water, ingress from atmosphere and from the degradation of cellulose in oil.

IEC 60422 “Category B” Limits for Moisture	
Classification	$\mu\text{l/l}$
Good	< 20
Fair	20 -30
Poor	> 30

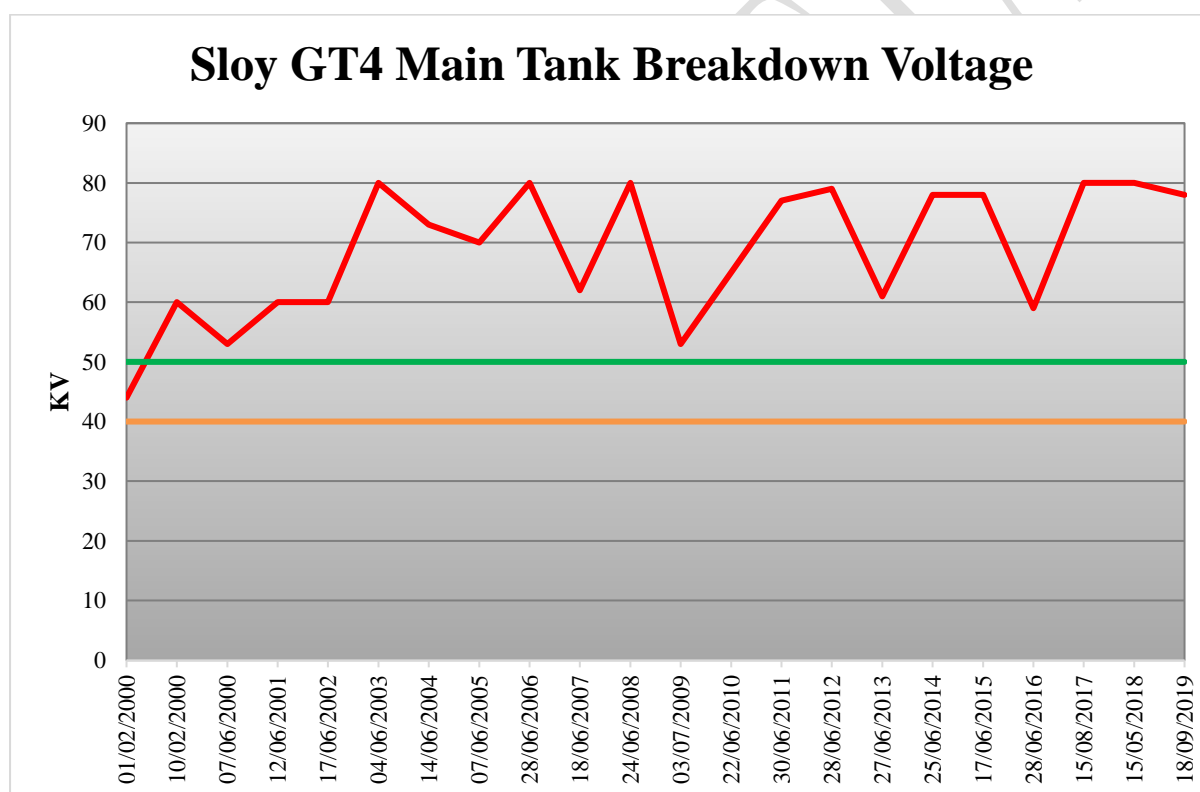


The historical moisture data span the period 2000 to 2019 and includes 22 samples. Over the operational life of the transformer the moisture levels are observed to be dynamic and, overall, exhibit an increasing trend. Moisture levels have predominantly been categorised as “Good”, as defined in IEC 60422 for category B apparatus, despite the overall increasing trend displayed. A substantial reduction in moisture levels between the first two samples in the range suggests re-conditioning of the main tank oil or poor sampling technique in the sample dated 1<sup>st</sup> of February 2000. The overall moisture trend is satisfactory.

## Breakdown Voltage

Breakdown voltage is a measure of the ability of the oil to withstand electric stress. Dry clean oil exhibits an inherently high breakdown voltage. Free water and other polar and non-polar contaminants reduce the breakdown voltage dramatically.

IEC 60422 “Category B” Limits for Breakdown Voltage	
Classification	kV
Good	> 50
Fair	40 - 50
Poor	< 40

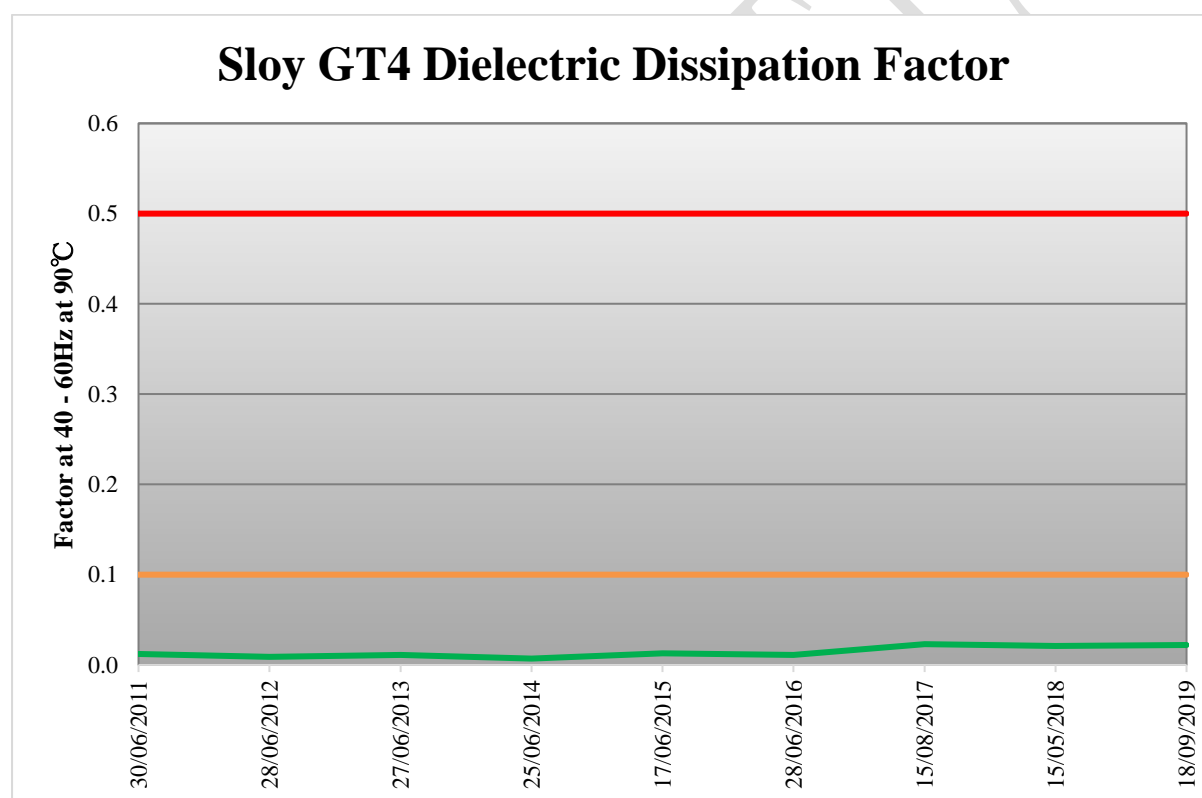


The historical breakdown voltage spans the period 2000 to 2019 and includes 22 samples. Over the sample period, the breakdown voltage is predominantly categorised as “Good”, as defined by IEC 60422. The overall trend exhibited is erratic however, a correlation between reduced breakdown voltage level and increased moisture levels are apparent in February 2000, June 2007, and June 2013. The most recent breakdown voltage is “Good” and is considered representative of the breakdown voltage history.

## Dielectric Dissipation Factor

The dielectric dissipation factor is sensitive to the presence of soluble polar contaminants and ageing products in the oil. Changes in the levels of contaminants can be monitored by this parameter even when the contamination is so low as to be near the limits of chemical detection.

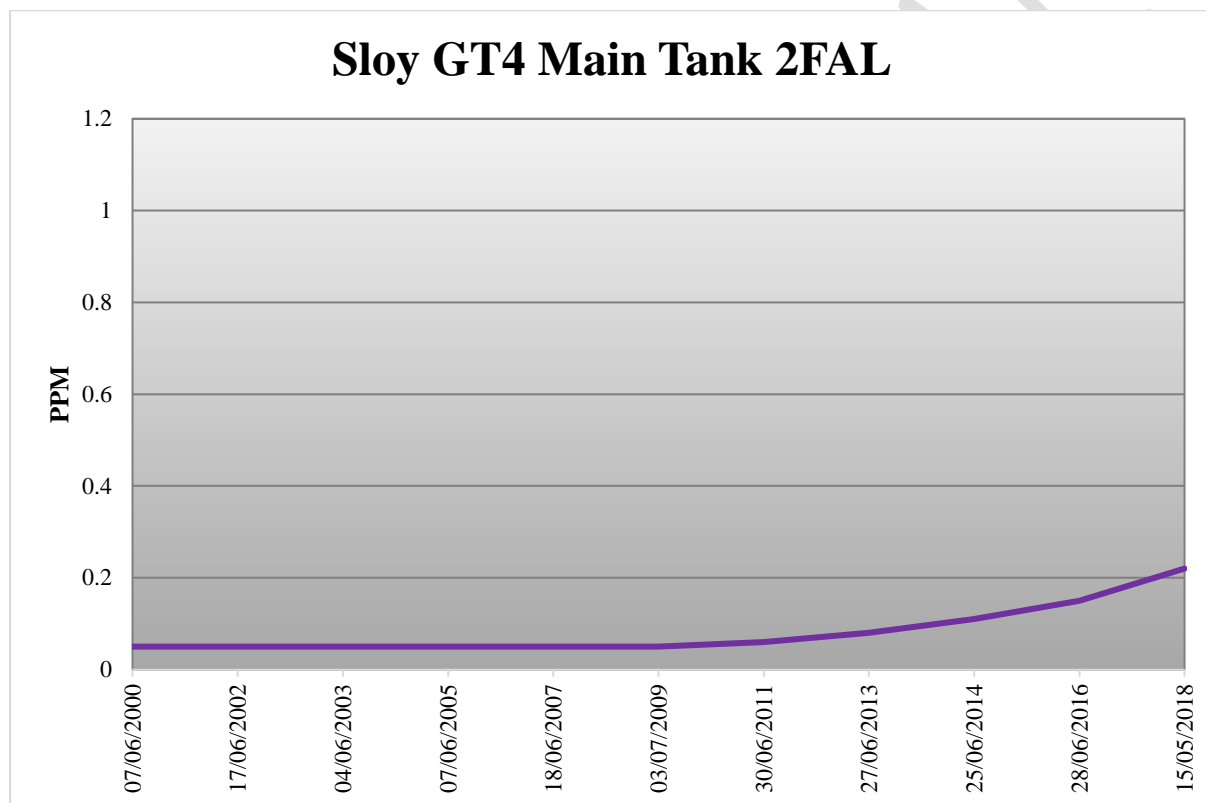
IEC 60422 “Category B” Limits for Dielectric Dissipation Factor	
Classification	kV
Good	< 0.1
Fair	0.1 – 0.5
Poor	> 0.5



The Dielectric Dissipation Factor level, as defined by IEC 60422, as “Good” and is satisfactory.

## 2FAL

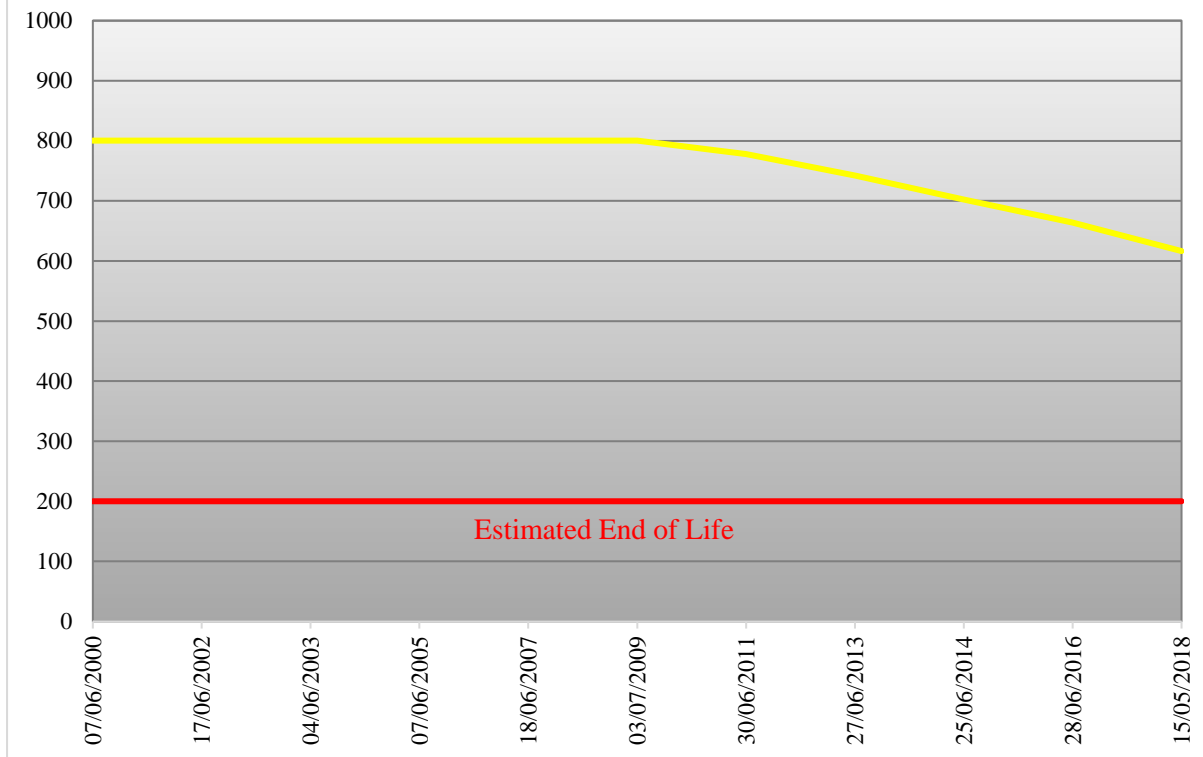
2FAL is a class of furanic compound produced by the degradation and breakdown of cellulose within the transformer. There is a correlation between the measurable 2FAL and the estimated degree of polymerisation (DP), the molecular mechanical strength of the paper within the transformer, although this should be used as an indicator. The 2FAL can be affected by temperature, moisture and acidity, which is not taken into account in the estimation algorithms used. The sampled oil may have been diluted or contaminated during in service operations, which would manifest as an overly optimistic estimated DP value and is therefore subjected to **high degree of uncertainty**.



The 2FAL record spans from 2000 until the most recent sample, which was taken in May 2018. The 2FAL level remains in a steady state until June 2011 where an increasing trend is exhibited over the remaining sample range. This increasing trend is indicative of increasing or accelerated insulation ageing. The final value recorded was 0.22 (Est DP 616), which also represents the highest value recorded throughout the historical sample range. The link between measured 2FAL and estimated DP is reliant on an algorithmic relationship, of which there are five different variants. The Chengdong algorithm has been used to relate measured 2FAL to estimated DP. In order to estimate the DP of the insulation system, the highest value of measured 2FAL shall be used (From May 2018). 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 in a reasonable condition.

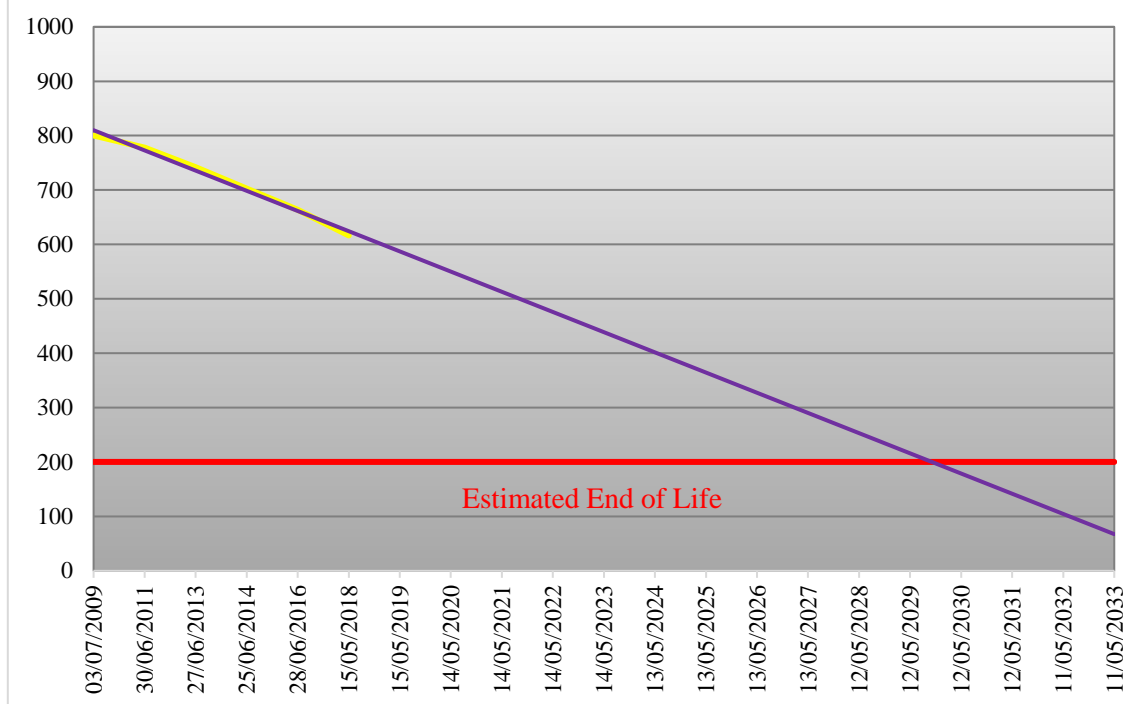


## Sloy GT4 Main Tank Estimated DP



Between 2009 and 2018 there is an almost linear and sustained ageing rate. Extrapolation of the estimated DP, 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.

## Sloy GT4 Main Tank Estimated DP Projected



### 132kV Bushings

Oil samples were taken from the A, B & C phase 132kV bushings (designated R, Y & B) in 2011 and sent to Peterhead oil laboratory for DGA and moisture analysis. The DGA and moisture analysis were assessed by SSEN using National Grid's "TGN 82 & 60422:2013"

### Bushings GT4 - DGA & Moisture

The tables below detail the results found for the DGA and moisture analysis as well as their respective categorisation in accordance with "TGN 82 & 60422:2013" documents.

Oil Parameter	Bushing		
	B	R	Y
Hydrogen (ppm)	10	8	7
Acetylene (ppm)	0	0	0
Ethane (ppm)	34	31	26
Methane (ppm)	9	9	8
Ethylene (ppm)	1	1.1	0
Water (ppm)	4	3	4

Key:

Category 1	Remove from system
Category 2	Controlled Maintenance
Category 3	Enhanced Maintenance
Category 4	Normal Maintenance

Oil Parameter	Bushing		
	B	R	Y
Breakdown Voltage (kV)	-	-	-
Water (ppm)	4	3	4
Acidity (mgKOH/g)	-	-	-

Key:

Good
Fair
Poor

The 132kV bushings dissolved gas analysis (DGA) quantities were all found to be at levels classified as “Category 4 – Normal Maintenance”, as defined by TGN 82. Moisture content in all bushings is categorised as “Good”, as defined by IEC 60422:2013.

The oil sampling frequency of the 132kV bushings remains at an interval of 12 years. The basic maintenance interval remains at the normal interval of 6 years.

## General

This section is compiled by making reference to the information contained within SSEN Report T2BP-ACR-0011 Revision 1.10 dated October 2019, henceforth referred to as the document.

## Previous Condition Assessments

Condition assessments have suggested that “additional maintenance” in the form of painting is required. Due to the lack of photographic evidence contained within the document it is not possible to assess the degree of paint wear and or corrosion on GT4. The iSIM inspection data for GT4 are classified as either category 1 (No visible quantifiable deterioration or damage) or category 2 (Apparent normal wear intervention to be done at the next refurbishment). This highlights that there are no immediate external interventions required on GT4.

## Partial Discharge Survey

The document reports that a partial discharge survey was conducted in December 2014 with no indication of partial discharge being found. A signal detected during this survey, in the vicinity of GT3, could not be pinpointed however, it was suggested a CCTV camera is the likely source of the signal. An ultrasonic & thermal inspection is also claimed to have been conducted however, no evidence from either is contained within the document therefore it is not possible to draw a conclusion from the results. There is no evidence of partial discharge in transformer GT4 as concluded from the DGA. It is noted that the generators were not operating at the time of the survey.

## Infra-Red Thermovision Survey

An infra-red thermovision survey was conducted in January 2017 with no abnormalities being found. It is not stated in document if this survey was completed whilst GT4 was under load. It would be anticipated that thermal abnormalities would present themselves in a clearer context whilst the transformer is under load.

## Impulse Protection

Transformer impulse protection is achieved by coordinating gaps fitted to the 132kV bushings.

## Load & Duty Cycle

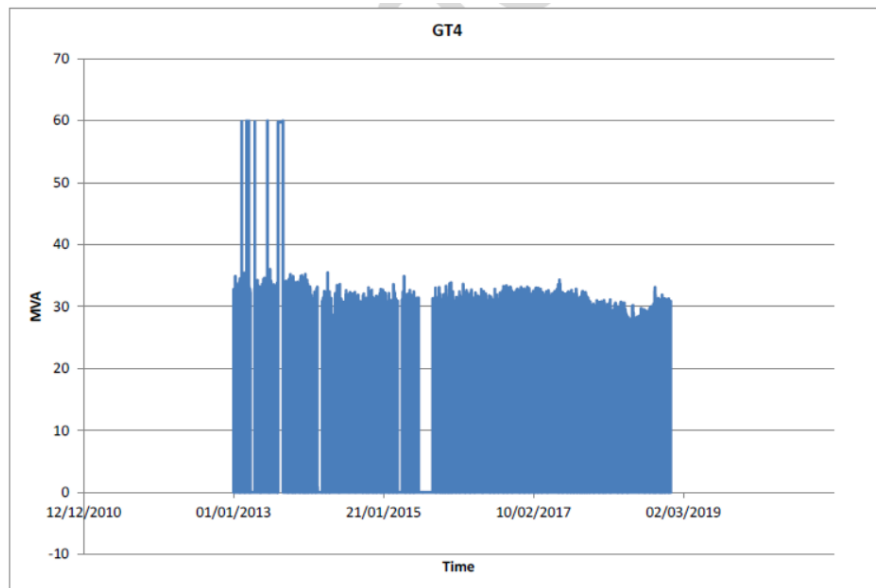


Figure 5.12 from section 5.6 of the document shows a measured load flow of GT4 for the period of 2013 to 2018. The transformer has a typical maximum load flow of around 35MVA, which is within the 50MVA rating of the transformer and at this load level the transformer would be operating in OFAF operation with the pumps and fans running.

In the period of July 2009 to May 2018 there is an increase in measured 2FAL indicative of accelerated the ageing of the paper insulation. Based on a linear relationship derived from historical DP results, GT4 can expect to be in operational condition for another 10 years.

## Historical Faults

27/08/2009 – GT4 cct tripped due to testing error resulting in 0.6MW load being lost. GT4 CT's shorted in error while injection testing on GT3. Testing suspended and GT4 returned to service.

25/08/2011 – T56 – When returning the Sloy substation to Sloy power station 132kV circuit SG4 to service after Sloy West busbar main CB 410 failed to close.

It is known that a number of short circuits have occurred on the 11kV busbars at Sloy substation since they were installed in the late 1990s.

## Maintenance

Maintenance details obtained from PLACAR indicate that routine maintenance has been carried out over the operational lifetime of GT4.

GT4 - MW 132kV Grid Transformer Maintenance - 25/03/2005

GT4 - MW 132kV Grid Transformer Maintenance - 06/10/2009

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## Conclusion

Visual condition assessments have suggested that “additional maintenance” in the form of painting is required. Due to the lack of photographic evidence contained within the document it is not possible to assess the degree of paint wear and or corrosion on GT1. The iSIM inspection data for GT4 are classified as either category 1 (No visible quantifiable deterioration or damage) or category 2 (Apparent normal wear intervention to be done at the next refurbishment). This highlights that there are no immediate external interventions required on GT4.

The DGA does not exhibit any evidence of partial discharge, discharge, or thermal abnormality. The DGA history can be described as benign. The CO exhibits a spike in 2017 which is consistent with ageing of the paper insulation.

The oil quality parameters comprising of moisture, breakdown voltage, acidity and DDF are all categorised as “Good” as defined by IEC 60422:2013 indicating that the insulating oil has good dielectric properties. Currently no oil intervention is required.

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 a reasonable condition. There is however an observable deterioration. Between 2009 and 2018 there is an almost linear and sustained ageing rate. Extrapolation of the estimated DP from that period, 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. “End of life” by ageing will be reached beyond the RIIIO T2 period.

The 132kV bushings dissolved gas analysis (DGA) quantities were all found to be at levels classified as “Category 4 – Normal Maintenance”, as defined by TGN 82. Moisture content in all bushings is categorised as “Good”, as defined by IEC 60422:2013.

The oil sampling frequency of the 132kV bushings remains at an interval of 12 years. The basic maintenance interval remains at the normal interval of 6 years.

The transformer has a typical maximum load flow of around 35MVA, which is within the 50MVA rating of the transformer and at this load level the transformer would be operating in OFAF operation with the pumps and fans running.

Faults on the 11kV busbars have the potential to cause mechanical distortion of the 11kV and 132kV transformer windings – depending on the feeding arrangement at the time of the fault. 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. It is possible that the 11kV windings on GT4 could be displaced or distorted causing a mechanical weakness in the transformer.

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. The transformer is deteriorating and should be kept under surveillance.

## Recommendations

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.