Sloy GT3 132/11kV Transformer

Level 1 Condition Assessment Report
15th July 2020
Report: SLOYGT3SHET200626 FINAL

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Polaris Diagnostics & Engineering Ltd

Contents

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 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. The 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.

Issue Record

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Issue Date	Issue No	Author	Amendments
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9th July 2020	DRAFT v2	MJ Gilfeather	Editorial & Clarifications
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Author	Issue Authority
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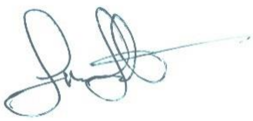
	

Review

This document is subject to review.

Condition Assessment Level

A level 1 condition assessment was carried out on Sloy GT3 132/11kV transformer as defined in the table below.

TRANSFORMER CONDITION ASSESSMENT				
LEVEL	**DESCRIPTION***	**SITE VISIT REQUIRED**	**OUTAGE REQUIRED**	**ASSESSMENT CLASS**
Level 1	Oil Data and History Provided by Client for Analysis	No	No	Basic
Level 2	Level 1 & Ground Based Visual Survey	Yes	No	Advanced Basic
Level 3	Level 2 & Non-invasive Surveillance (Thermal Survey/RFI Scan of Transformer)	Yes	No	Intermediate
Level 4	Level 3 & Independent Oil Sampling and Analysis in Accordance with IEC 60422	Yes	No	Advanced
Level 5	Level 4 & Overall Visual Survey	Yes	1 day outage	Detailed
Level 6	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 M0003

This transformer was manufactured in 1996, and was installed and commissioned at Sloy 132kV substation.

Sloy GT3 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

Manufacturer:	Peebles Power Transformer
Serial Number:	M0003
Year of Manufacture:	1996
ONAN/OFAF Rating:	25/50 MVA
Ratio:	132/11 kV
Vector Group:	Unknown
Impedance:	Unknown
Tap Changer Manufacturer:	ATL
Tap changer Type:	307/500 A250 LSP
Tap Changer Serial Number:	Unknown
HV Bushings:	Unknown
Oil Type:	Uninhibited, unknown type
Breather Type:	Free Breathing
Moisture Management:	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 historical defects associated with the design of this transformer.

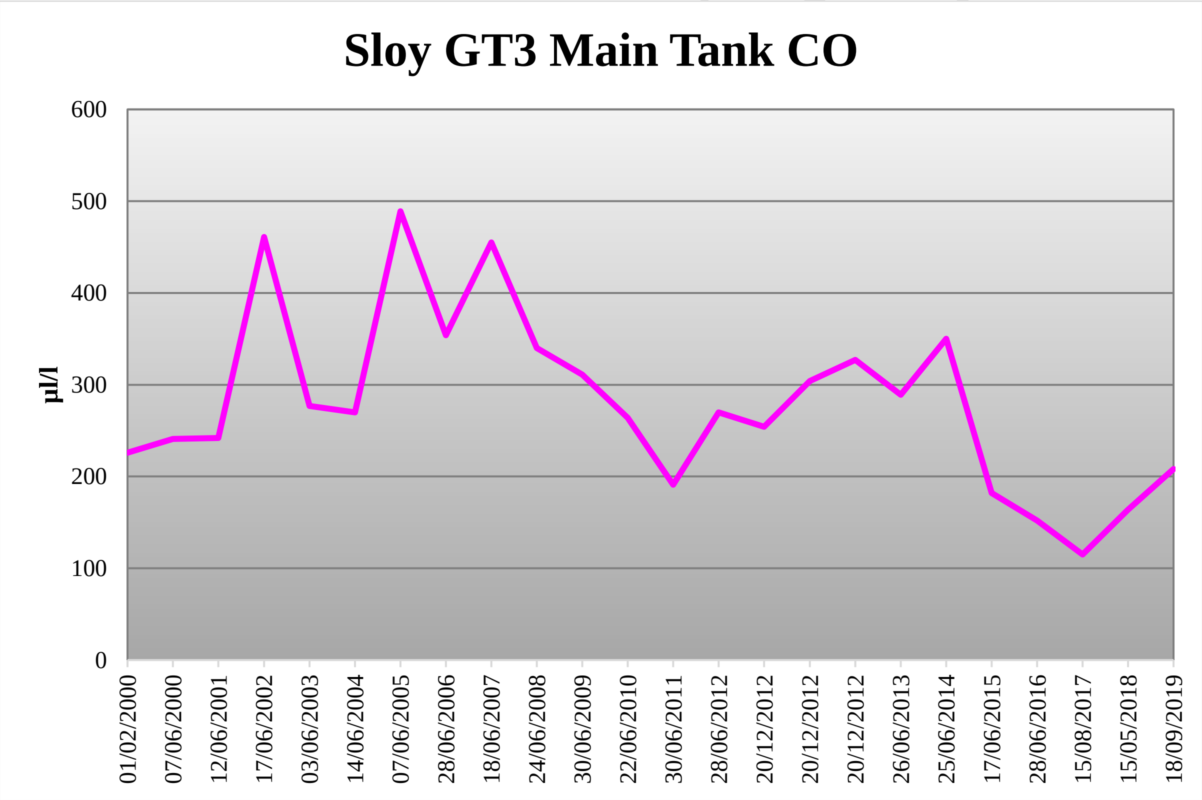
Main Tank Oil History

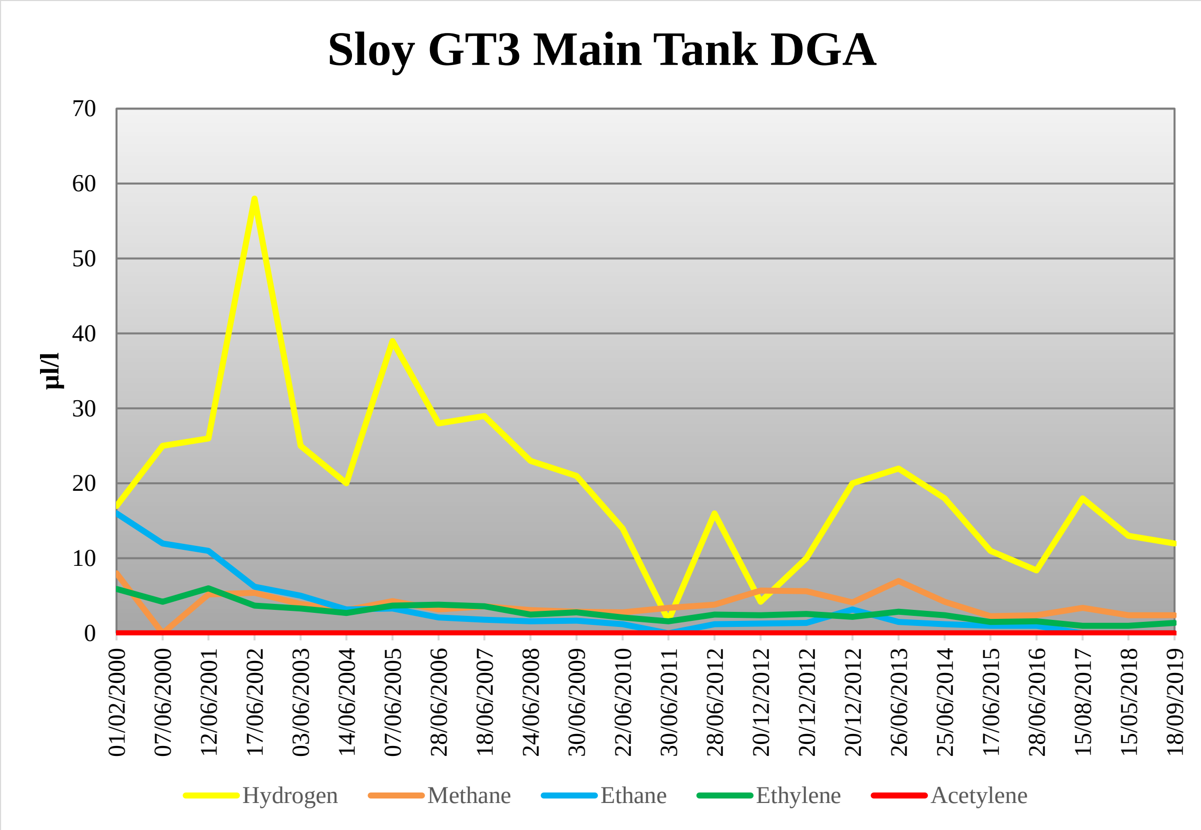
Dissolved Gas Analysis – Main Tank History

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 considered erratic with short periods of accelerated rates of CO generation indicative cellulose degradation yet, CO values remain below “typical values” specified in IEC 60599 over the sample period, peaking at 489µl/l in 2005. The paper insulation is likely to be in an aged condition.





Hydrogen and the thermal gases methane, ethane and ethylene are all present in the DGA history. 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, 0.16, undefined] fails to highlight any abnormality with the diagnosis being a non-classification. Using the Duval's triangle method of DGA interpretation, the same gas ratios define a "T2" condition, "Thermal faults, 300℃ < T < 700℃', however, it should be noted that the Duval method, being a closed system, will always result in a condition being identified. 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

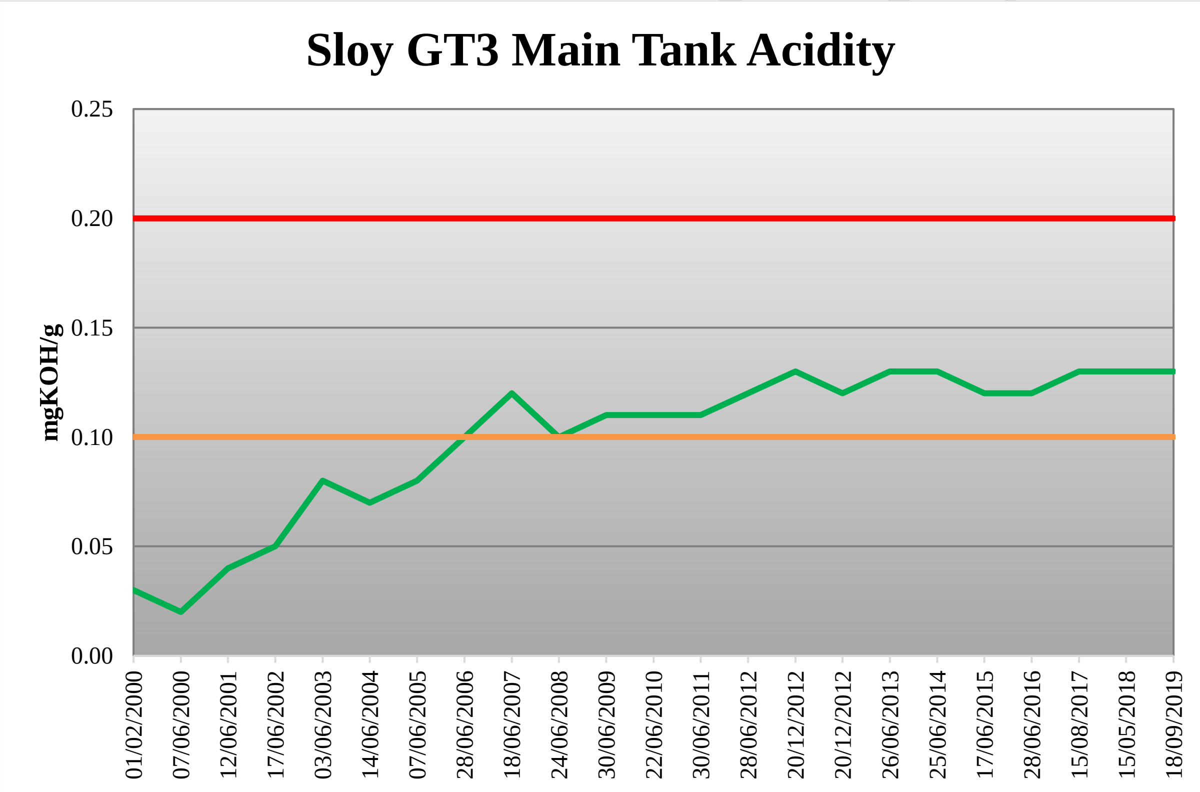
Main Tank Oil Quality Analysis

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.

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**

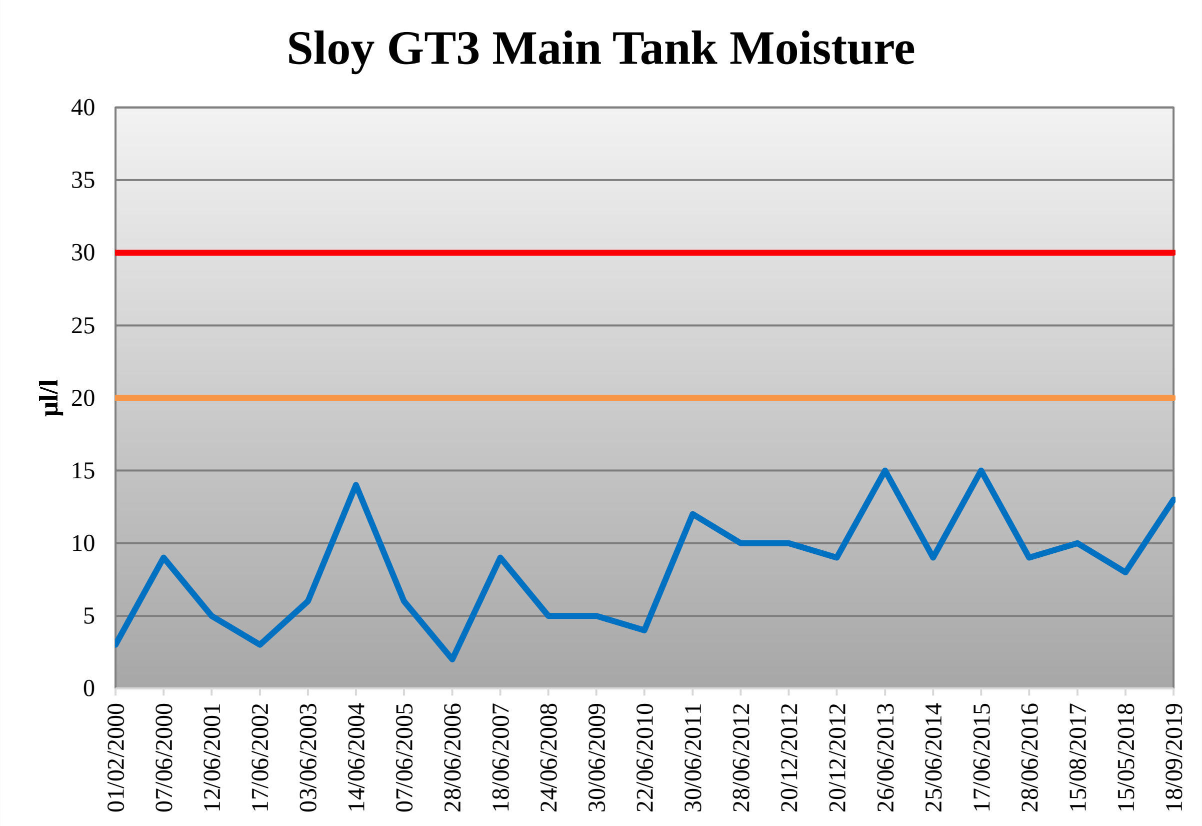


The historical acidity record has 23 samples taken in the period of 2000 to 2019. The acidity levels are found to be increasing over the sample range, indicative of oxidation of the oil. In the period of 2000 to 2005 all samples are categorised as "Good" as defined by IEC 60422 for category B apparatus, despite a clear increasing trend. The remaining samples, from 2006 to 2019 are all categorised as "Fair" and overall an increasing trend is exhibited. The acidity is considered acceptable, but to restore the acid concentrations to a level defined as "Good", the oil would require to be regenerated.

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	**µl/l**
Good	**< 20**
Fair	**20 -30**
Poor	**> 30**

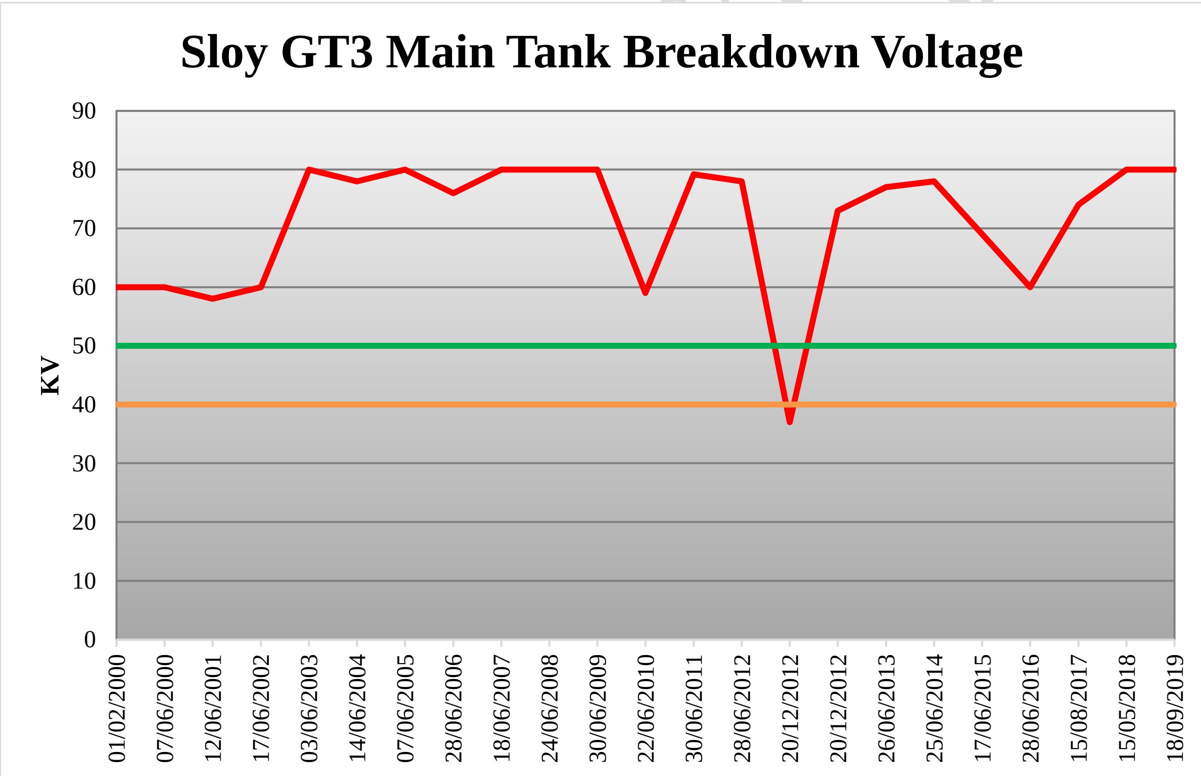


The historical moisture data spans 23 samples taken over the period of 2000 to the most recent sample in 2019. Over the operational life of the transformer the moisture levels are observed to be dynamic yet, moisture levels have consistently been categorised as "Good" as defined in IEC 60422, for category B apparatus. Moisture levels peak at 15µl/l in 2013 & 2015. The overall moisture trend is considered 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**

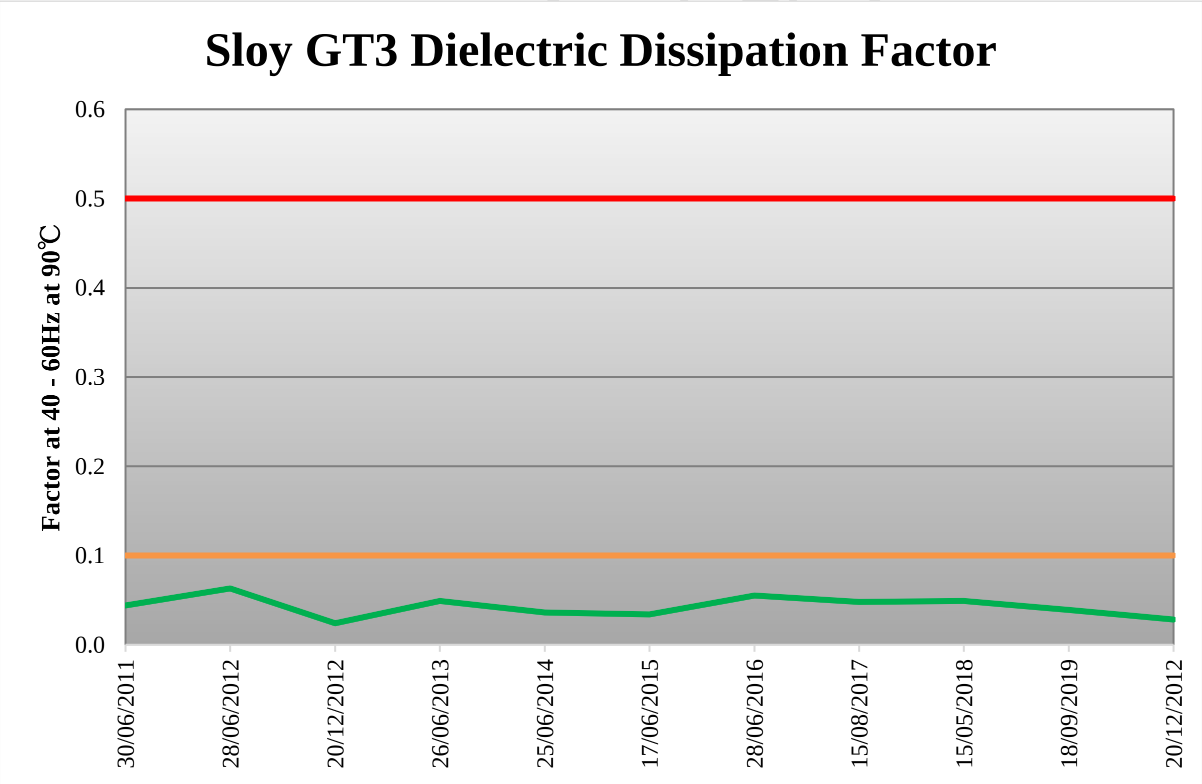


The historical breakdown voltage record spans from 2000 to the most recent sample in 2019. Over the available history, the breakdown voltage is predominantly categorised as "Good" as defined by IEC 60422. The trend exhibited is dynamic with the lowest value of 37kV recorded in December of 2012. This is considered to be due to poor sampling procedure or technique as a repeat sample taken on the same date returns a breakdown voltage level of 73kV. No correlations in reductions of breakdown voltage and increased measured moisture are observed. The most recent breakdown voltage is categorised as "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.

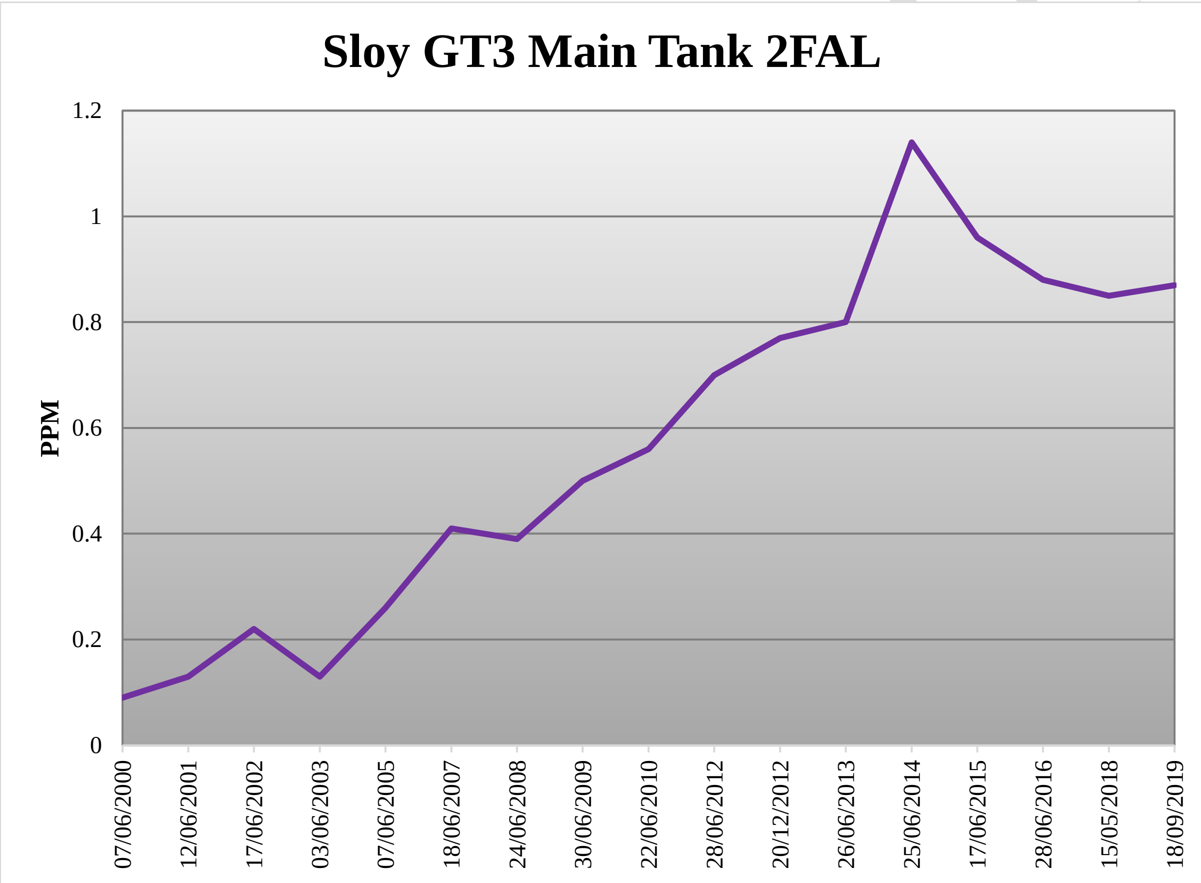
IEC 60422 "Category B" Limits for Dielectric Dissipation Factor	
Classification	**kV**
Good	**< 0.1**
Fair	**0.1 – 0.5**
Poor	**> 0.5**



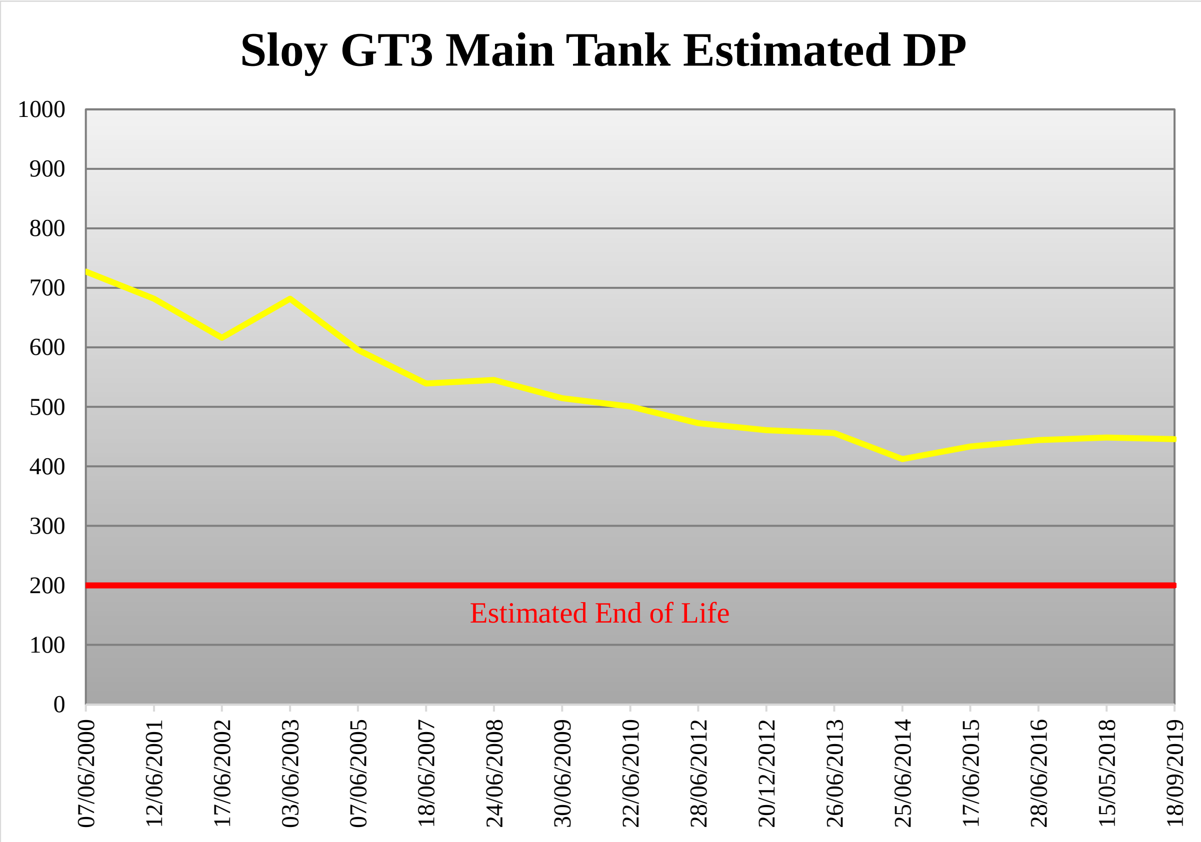
The Dielectric Dissipation Factor level, as defined by IEC 60422, is "Good" and is satisfactory.

2FAL

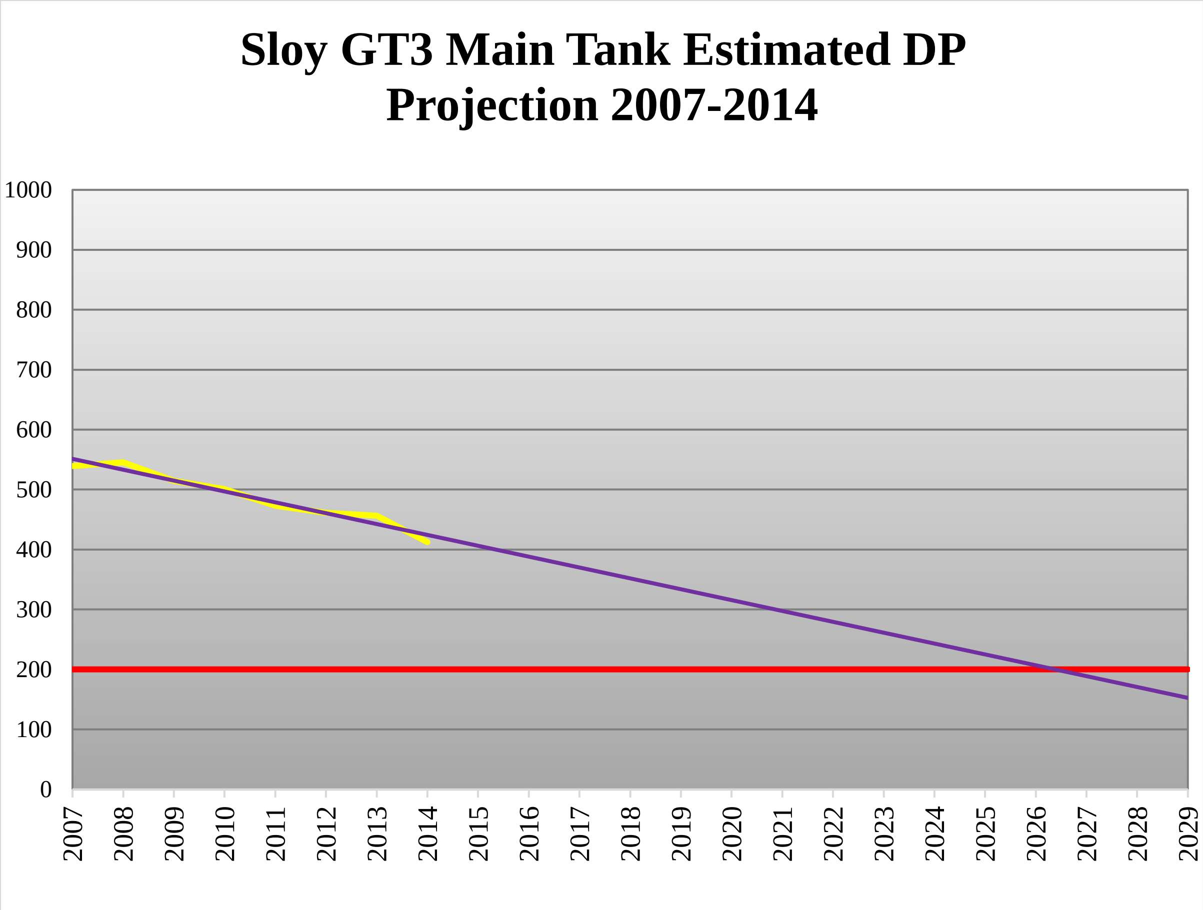
2FAL is a class of furanic compound produced by the degradation and breakdown of cellulose within the transformer. There is a correlation between the measurable 2FAL and the estimated degree of polymerisation (DP), the molecular mechanical strength of the paper within the transformer, although this should 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 historical record spans from 2000 until the most recent sample, taken in September 2019. The 2FAL levels, overall, show an increasing trend over the sample period which is indicative of increasing or accelerated insulation ageing, which is particularly prominent between 2013 and 2014. A reduction in 2FAL levels between 2015 & 2018 is indicative of a dilution to the main tank oil by means of oil top ups or by oil processing. The final value recorded was 0.87 (Est DP 446), compared to the highest value recorded in the sampling period of 1.14 (Est DP 412). 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 June 2014). 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 suggests that the paper insulation is in an aged condition.



Between 2007 and 2014 there is an almost linear and sustained ageing rate, which is considered to be genuine. The 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.


Sloy GT3 Main Tank Estimated DP Projection 2007-2014
1000
900
800
700
600
500
400
300
200
100
0
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029

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 GT3 - 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)	2	9	5
Acetylene (ppm)	0	0	0
Ethane (ppm)	93	111	92
Methane (ppm)	20	23	20
Ethylene (ppm)	1.4	1.5	1.2
Water (ppm)	5	5	6

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)	5	5	6
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 3 – Enhanced 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 should be every 6 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 GT3. The iSIM inspection data for GT3 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 GT3.

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 GT2 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 GT2 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

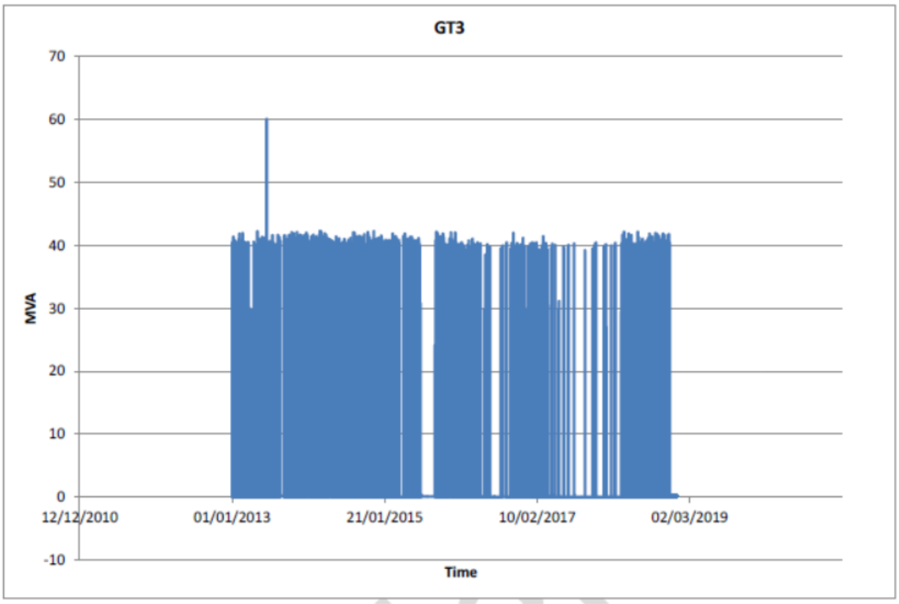


Figure 5.11 from section 5.6 of the document shows a measured load flow of GT3 for the period of 2013 to 2018. The transformer has a typical maximum load flow of around 42MVA, which is within the 50MVA rating of the transformer and at this load level the transformer would be operating in OFAF operation with the pumps and fans running. The step change duty cycle and high levels of loading of the transformer do not appear to have caused step changes in the generation of 2FAL, but there is evidence from the 2FAL that paper insulation is ageing.

Historical Faults

25/09/2006 – GT3 tripped causing 30mw of lost generation. This was due to an 11kV busbar fault. Blown hole found on Moser-Glaser busbar in Y-phase terminal box of earthing transformer. Water accumulation observed in terminal box likely due to water ingress at weather shroud.

03/07/2009 – Trip & lockout due to lightening activity. Returned to service via telecontrol.

14/07/2011 – GT3 inter-trip on circuit-breaker 390 during generation run test.

18/12/2012 – GT3 tripped on circuit breaker 390. GT3 was inspected and no damage was observed yet it failed to Re-close as it tripped immediately. Moser Glaser connection found to be faulty, subsequently replaced with Polymeric cable.

02/10/2015 – GT3 tripped when Sloy Power Station performed a Portal Valve trip test. 3GO was slow to open which caused intertrip to be sent to Sloy GIS to trip circuit.

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.

Emergency Oil Samples

Oil samples taken in December of 2012 from the main tank, main tank top and buchholz relay due to the fault experienced at this date, detailed in the previous section. Breakdown voltage was substantially reduced (37kV) in this sample. No explanation is given in the document as to how this moisture content was reduced in the following sample, no record of re-conditioning of the main tank oil is observed in the document.

Maintenance

Maintenance details obtained from PLACAR indicate that routine maintenance has been carried out over the operational lifetime of GT3.

GT3 - MW 132kV Grid Transformer Maintenance - 28/11/2007

GT3 - MW 132kV Grid Transformer Maintenance - 29/07/2015

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 GT3. The iSIM inspection data for GT3 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 GT3.

The DGA does not exhibit any evidence of partial discharge, discharge, or thermal abnormality. The DGA history can be described as benign. The historical CO characteristic is erratic but exhibits sharp increases in CO generation which is consistent with the ageing of cellulose insulation.

The oil quality parameters comprising of moisture, breakdown voltage, and DDF are all categorised as “Good” as defined by IEC 60422:2013 indicating that the insulating oil has good dielectric properties. The acidity of the oil has deteriorated to a “Fair” category as define by IEC 60422:2013 indicating that the oil is oxidised. The main tank oil would require to be regenerated to restore the acidity levels to what would be defined as “Good”.

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. The 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.

The 132kV bushings dissolved gas analysis (DGA) quantities were all found to be at levels classified as “Category 3 – Enhanced 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 should be reduced to an interval of 6 years. The basic maintenance interval remains at the normal interval of 6 years.

The transformer has a typical maximum load flow of around 42MVA, 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.

A fault on the 11kV cable termination (25/09/06) has 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 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.

This transformer should be planned for replacement.

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.