Aigas GT1 132/11kV Transformer

Level 1 Condition Assessment Report 16th July 2020 Report: AIGASGT1SHET200629 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 Aigas GT1 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-0020 Revision 1.1 dated November 2019,both supplied by SHE Transmission.

Based on the assessment of the historical & current asset condition data, GT1 is in a condition commensurate with age and the transformer condition will continue to deteriorate, by ageing, during the RIIO T2 period. There is an increased risk of failure of the asset within this period due to an underlying thermal abnormality and oil leakage. Further intervention will be required within the RIIO-T2 period to mitigate this increased risk of failure.

There is evidence that the transformer has externally deteriorated and requires further inspection and evaluation. Given that the transformer is located in close proximity to the River Beauly, the transformer should be considered as an environmental hazard until such times as the oil leaks have been repaired or the transformer is replaced.

There is an underlying thermal abnormality as evidenced by the presence of dissolved ethylene levels in both the main tank and tap changer selector. These are communicating and in equilibrium. To identify of the source of the dissolved ethylene electrical testing would be required. Whilst these magnitudes of dissolved gases are still at low level, the dissolved ethylene should be kept under surveillance, in order to check for further manifestation on what could become degenerative thermal abnormality.

Oil processing or topping up of the main tank oil has had a dilution effect on the measured 2FAL concentrations and as this is used to predict the condition of the paper insulation and "estimated residual life remaining" of that insulation, the estimate of 55% life remaining is considered optimistic.

This transformer is internally in "reasonable condition" but has an underlying thermal abnormality and will require monitoring in the form of increased oil surveillance and may require enhanced maintenance within this period to prevent deterioration that may lead to failure. The external condition is aged. The transformer has active oil leaks. A 'mid-life' refurbishment should be considered in order to return the asset to a condition such that it will extend the asset life.

In order to mitigate the risk of an increased likelihood of failure during the RIIO T2 period and to understand the scope of work for a "mid-life" refurbishment, the following recommendations are made:

- Frequency of oil sampling should be increased to monitor dissolved ethylene, moisture content and dielectric breakdown voltage. This should be done every 6 months.
- The transformer will require to be cleaned down to mitigate the health and safety risk from bird droppings to facilitate a detailed inspection.
- Detailed inspection of the asset – outage required – to identify the source of the oil leaks.
- Inspection and assessment of the moisture management system.
- 132kV bushings should be oil sampled for DGA and moisture analysis and assessed by the criteria set out in National Grid TGN 82. In addition the bushing power factor and capacitance

should be measured. This would require an outage and the removal of the 132kV and 11kV bushings to facilitate the testing.

- Detailed condition assessment of the transformer to include Sweep Frequency Response Analysis (SFRA), Dielectric Frequency Response (DFR), 10kV Power Factor, 5kV Insulation Resistance and DC Winding Resistance testing. This would require an outage and the removal of the 132kV and 11kV bushings to facilitate the testing.
- Following detailed inspection continue with routine inspection.
- Continue with routine maintenance.
- Detailed load flow monitoring.

Issue Record

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Issue Date	Issue No	Author	Amendments
29th June 2020	DRAFT	MJ Gilfeather	-
12th July 2020	DRAFT v2	MJ Gilfeather	Editorials & Clarifications
16th July 2020	FINAL	IBB Hunter	Editorials & Alteration to 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.

Condition Assessment Level

A level 1 condition assessment was carried out on Aigas GT1 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 40734

This transformer was manufactured in 1960, and was installed and commissioned at Aigas 132kV substation

Electrical Plant Details

Manufacturer:	Bruce Peebles
Serial Number:	40734
Year of Manufacture:	1960
ONAN Rating:	22.5 MVA
Ratio:	132/11 kV
Vector Group:	Unknown
Impedance:	Unknown
Tap Changer Manufacturer:	Fuller Electric
Tap changer Type:	HS315/33/200 DNL1
Tap Changer Serial Number:	104162
HV Bushings:	Unknown
Oil Type:	Uninhibited, unknown type
Breather Type:	Free Breathing
Moisture Management:	Unknown

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.

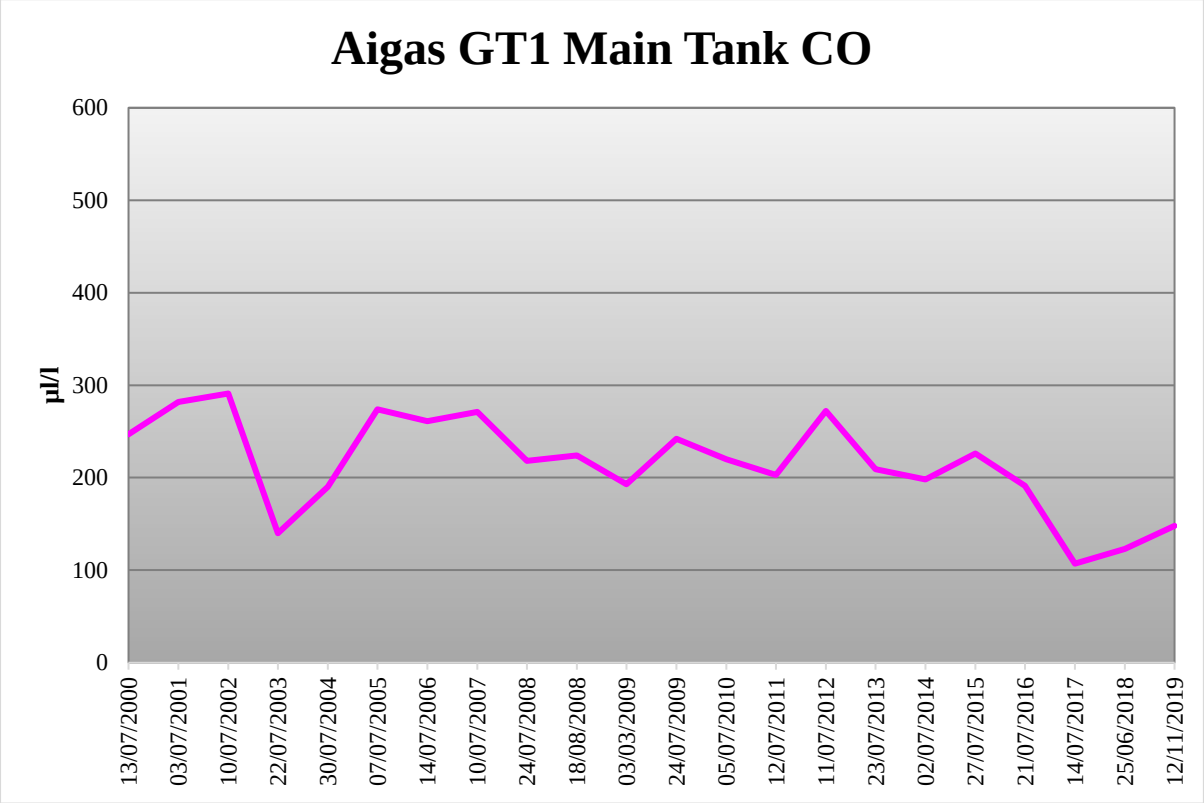
Main Tank Oil History

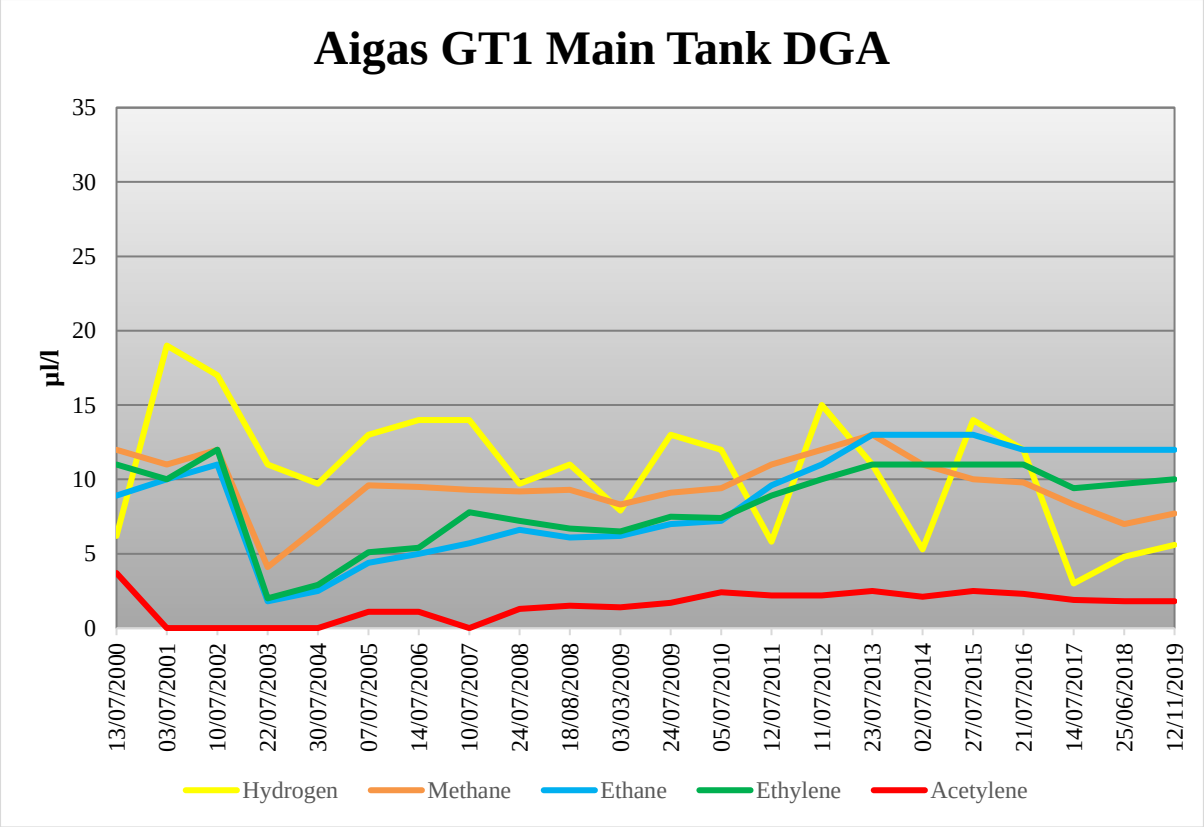
Dissolved Gas Analysis – Main Tank History

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 dynamic and exhibits an, overall, decreasing trend. All Values remain below "typical values" specified in IEC 60599 over the sample period, peaking at 291µl/l in 2002. The paper insulation is likely in reasonable condition for its age.





All diagnostic gases are present throughout the DGA history however, all remain at levels well below "typical values" specified in IEC 60599.

Application of the gas ratios, as defined in IEC 60599, [0.18, 1.3, 0.83] diagnoses a "T1" fault condition, defined as a "Thermal fault < 300℃'. Using the Duval's triangle method of DGA interpretation, the same gas ratios define a "T3" condition, "Thermal faults, T > 700℃', however, it should be noted that with 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 with the IEC methodology.

The DGA does not exhibit any evidence of partial discharge or discharge abnormality, however there is a trend of dissolved ethylene, which is indicative of a thermal abnormality, which is low level at this stage but has been present throughout the DGA history. Assuming that the main tank and tap changer are communicating there is a degree of equilibrium between the main tank and tap changer dissolved ethylene levels. To identify of the source of the dissolved ethylene electrical testing would be required.

Thermal Events:

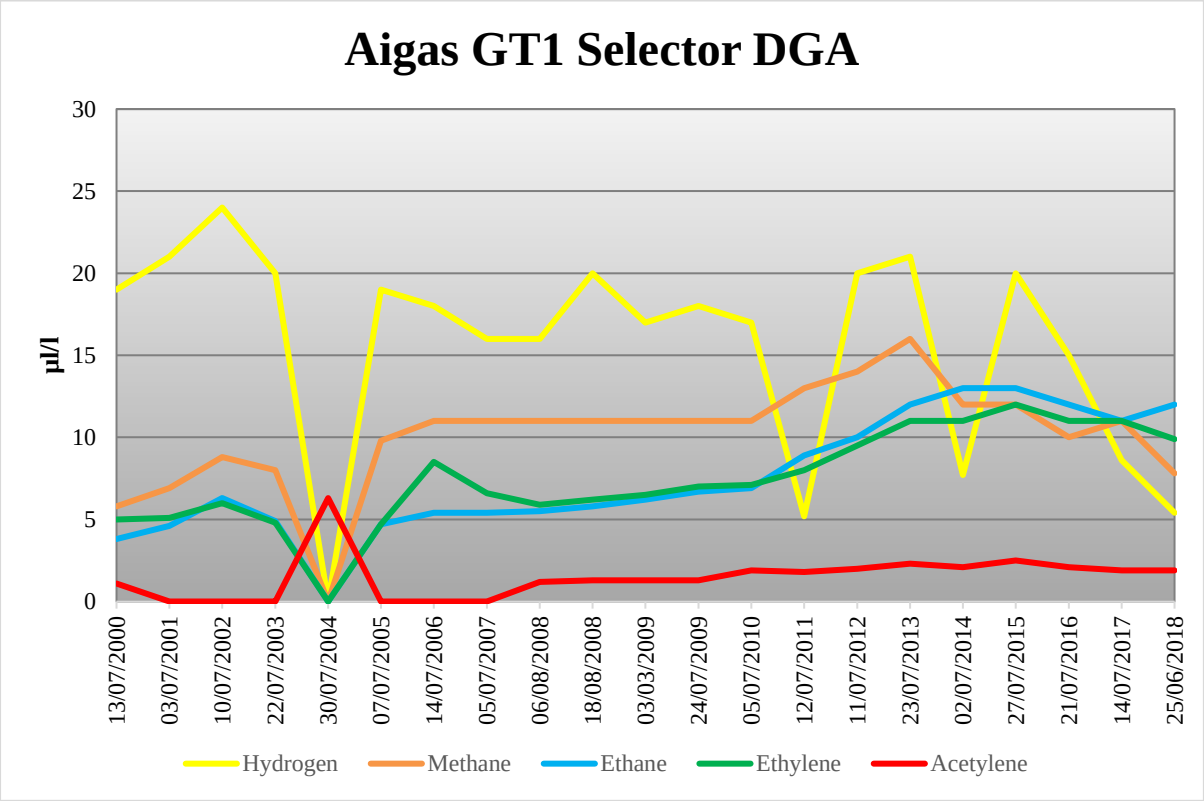
None. Dissolved ethylene should be kept under surveillance.

Discharge Events:

None. It should be noted that there is a presence of dissolved acetylene.

Dissolved Gas Analysis-Tap Changer Selector

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".



Application of the gas ratios, as defined in IEC 60599, [0.19,1.6,0.825], highlights a "T1" fault condition characterised by "Thermal fault < 300℃", although it should be noted that all diagnostic gases are well below the "typical values" as quoted in the standard. Using the Duval's triangle method of DGA interpretation, the same gas ratios define a "T3" condition, "Thermal faults, T > 700℃", however, it should be noted that the Duval method being a closed system will always result in a condition being identified. There has been a tap changer maintenance in 2004 as characterised by the simultaneous reduction in dissolved gases.

The DGA does not exhibit any evidence of partial discharge or discharge abnormality, however there is a trend of dissolved ethylene, which is indicative of a thermal abnormality, which is low level at this stage but has been present throughout the DGA history. Assuming that the main tank and tap changer are communicating there is a degree of equilibrium between the main tank and tap changer dissolved ethylene levels. To identify of the source of the dissolved ethylene electrical testing would be required.

Thermal Events:

None. Dissolved ethylene should be kept under surveillance.

Discharge Events:

None. It should be noted that there is a presence of dissolved acetylene.

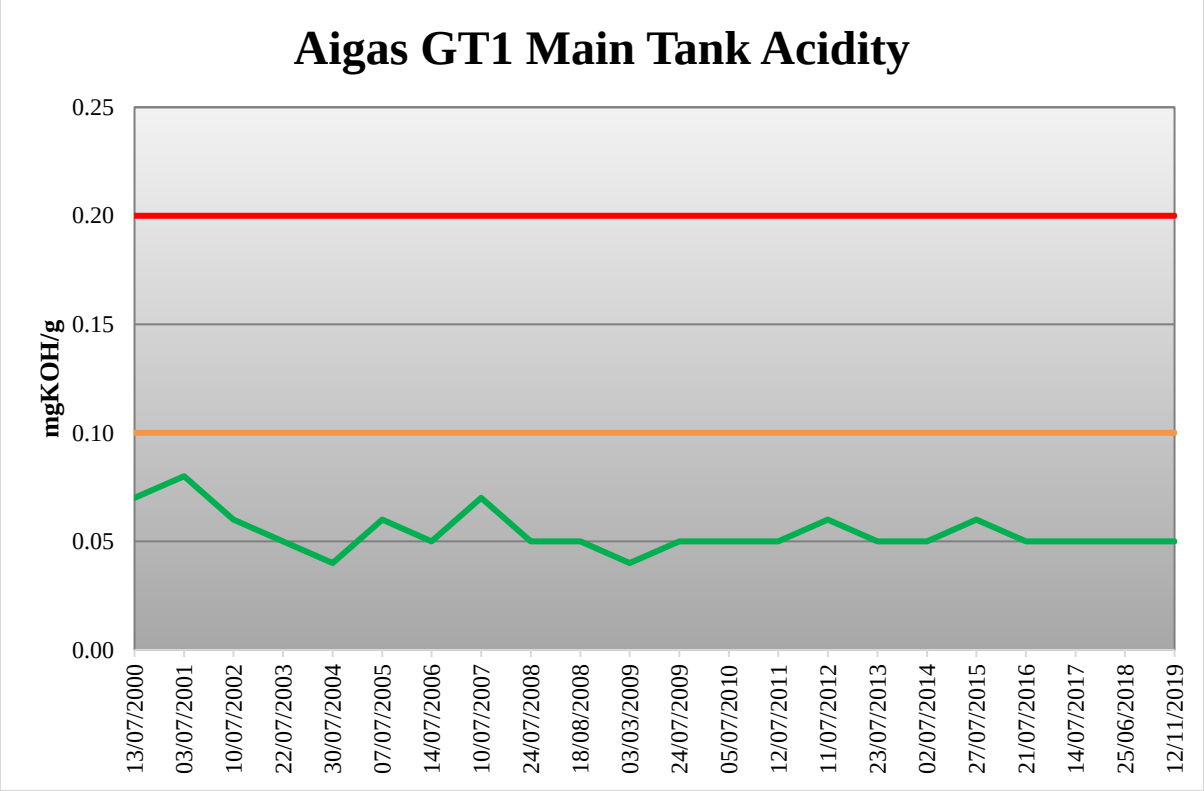
Main Tank Oil Quality Analysis

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.

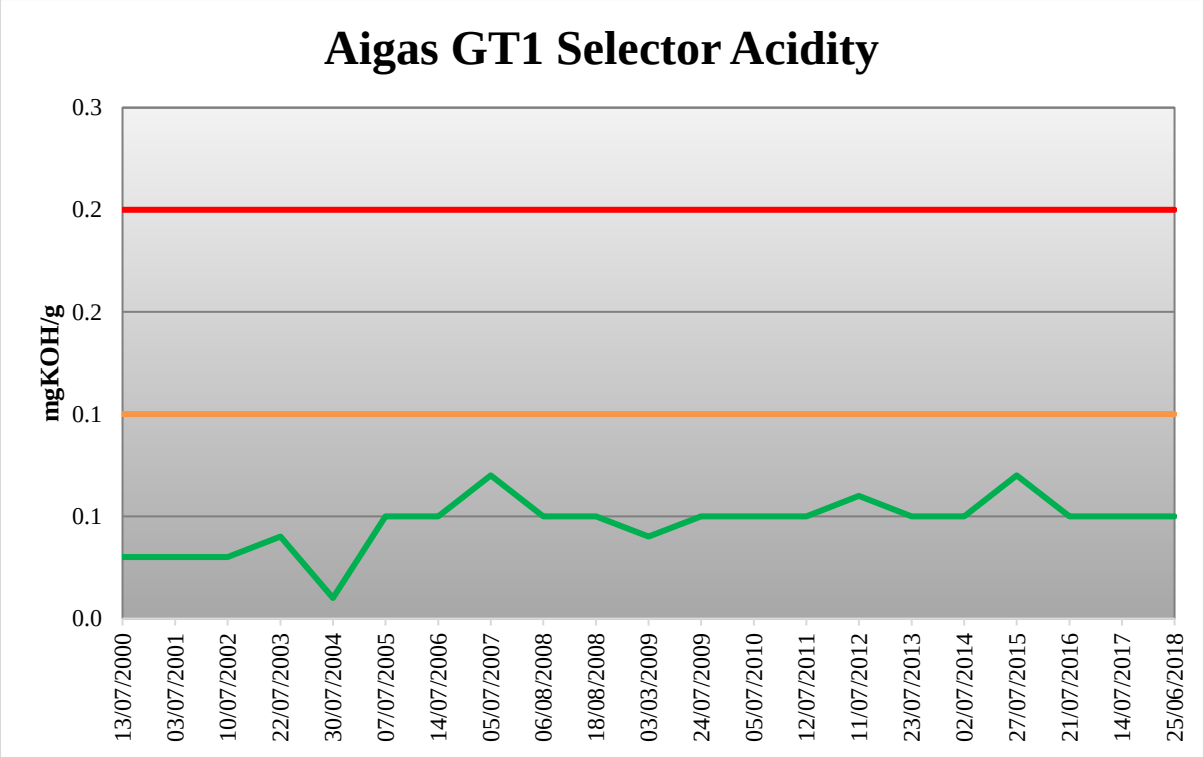
Acidity

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 spans the period of 2000 to 2019 and includes 22 samples. The acidity levels are found to be relatively stable over the sample period however, a reduction in acidity levels between July 2001 & July 2002 could be indicative of a dilution of the main tank oil by means of oil top ups. Acidity levels are consistently categorised as "Good" as defined by IEC 60422. The most recent acidity result of 0.05 mgKOH/g is satisfactory and considered representative of recent historical results.

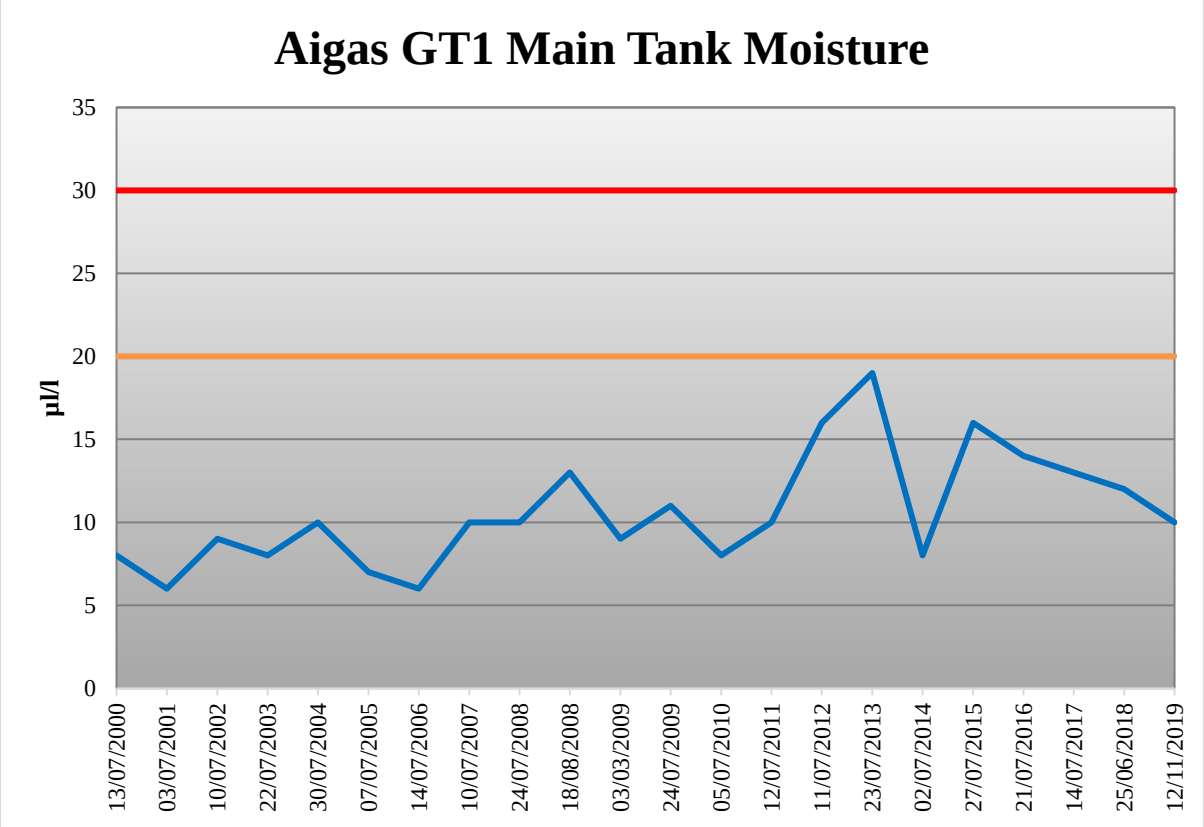


The historical selector acidity record contains 21 samples taken in the period of 2000 to 2018. The acidity levels are, overall, relatively stable and all samples in the historical range are categorised as "Good" as defined by IEC 60422. The most recent acidity result of satisfactory and considered representative of recent historical results.

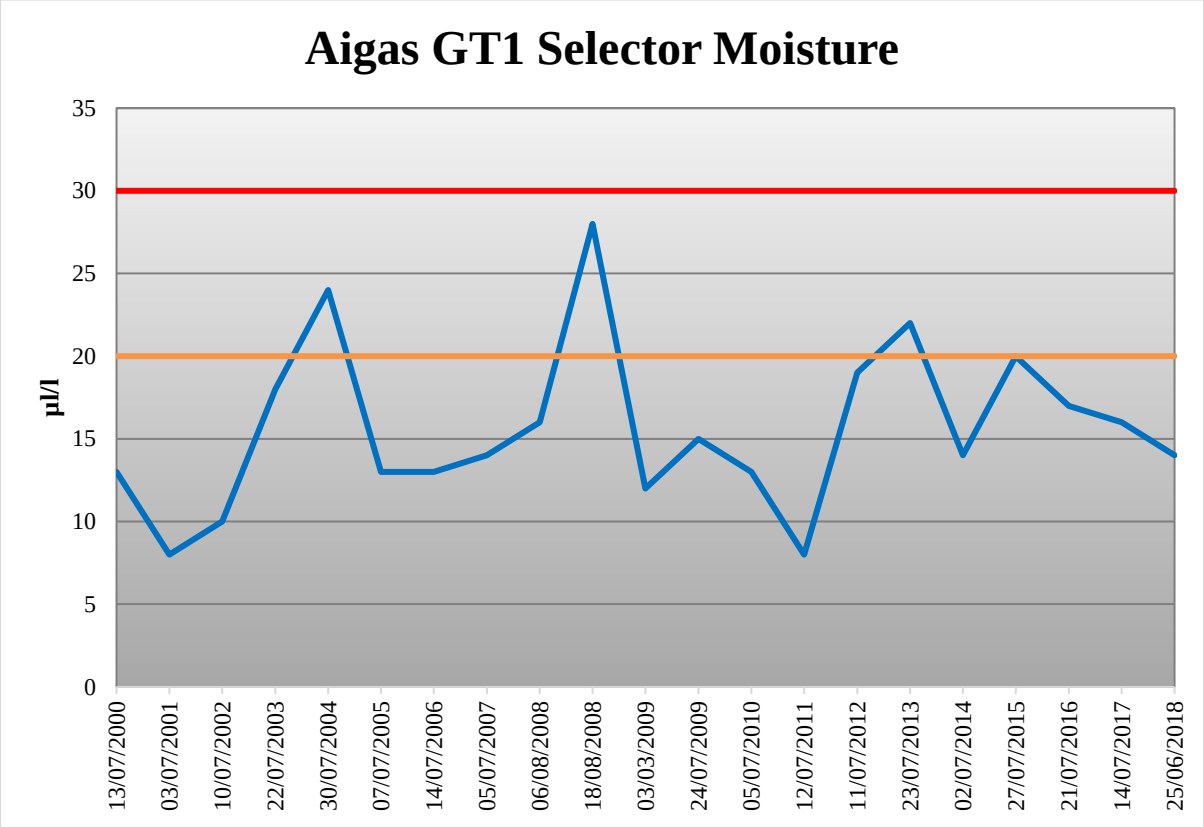
Moisture

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 22 samples over the period of 2000 to 2019. Over the operational lifetime of the transformer the moisture levels have exhibited a dynamic characteristic which, overall exhibits an increasing trend. All moisture results are categorised as "Good" as defined by IEC 60422, for category B apparatus. Moisture levels peak in July 2013 at 19µl/l. The most recent moisture result of 10µl/l is categorised as "Good" and is representative of historical moisture.



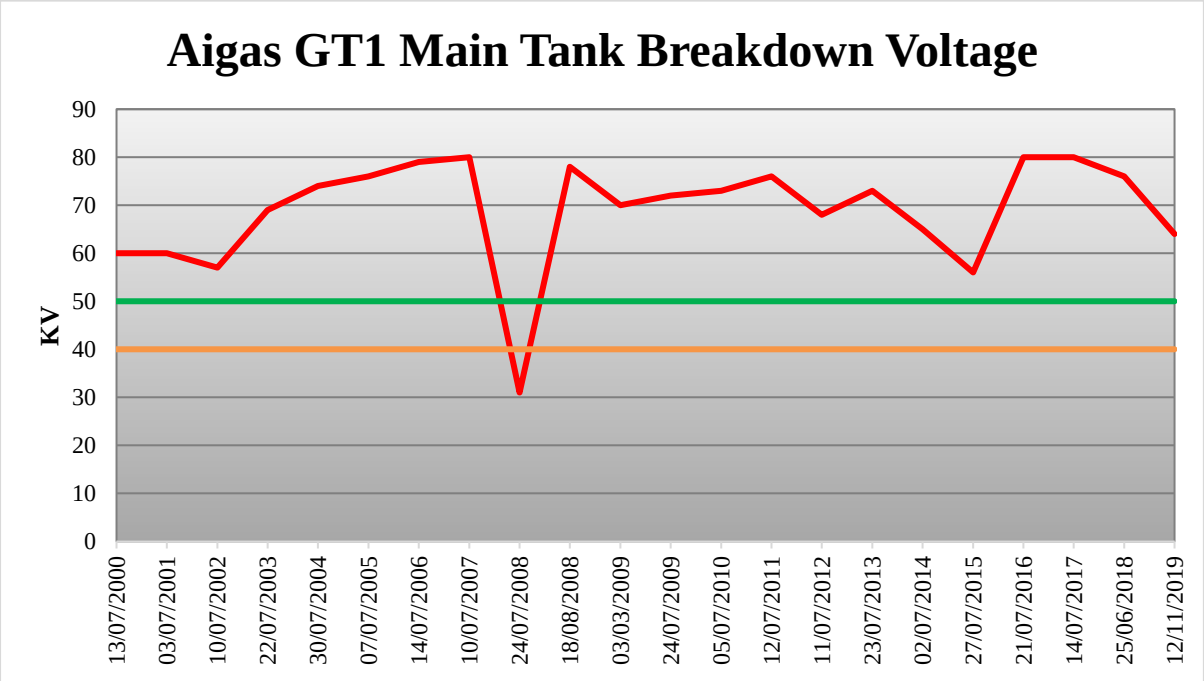
The historical selector moisture data spans 21 samples over the period of 2000 to 2020. Over the operational life of the selector moisture levels have been dynamic, this has resulted in a fluctuation between a categorisation of "Good" & "Fair", as defined by IEC 60422. Correlation in moisture peaks between the selector & the main tank are observed at each peak moisture value dated, July 2004, August 2008, July 2013 & July 2015 indicating that the tap changer oil is communicating with the main tank. Peak moisture value in the selector is recorded as 28µl/l in August 2008.

This would suggest that selector moisture management should be improved.

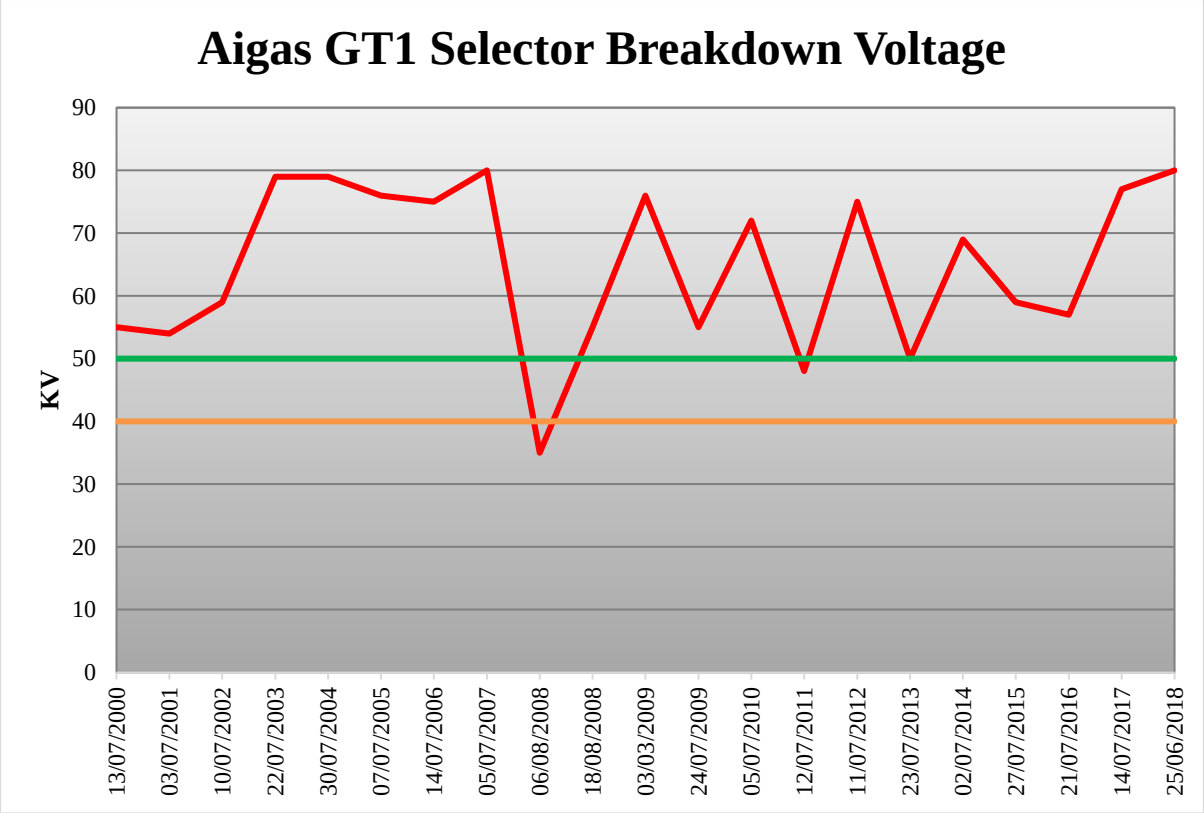
Breakdown Voltage

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 the period of 2000 to 2019 and is inclusive of 22 samples. Except for the result from July 2008 (31kV) categorised as "Poor", all breakdown voltage levels are "Good" as defined by IEC 60422. The reduction in breakdown voltage in July 2008 is likely the result of poor sampling techniques as the following sample, taken 3 weeks later, records a "Good" breakdown voltage level of 78kV. No correlation between substantial increases in main tank moisture levels are observed in July 2008. Reduction in breakdown voltage results from July 2015 correlates with increased moisture levels within the main tank. A dynamic trend is exhibited by breakdown voltage levels however, overall results are satisfactory.

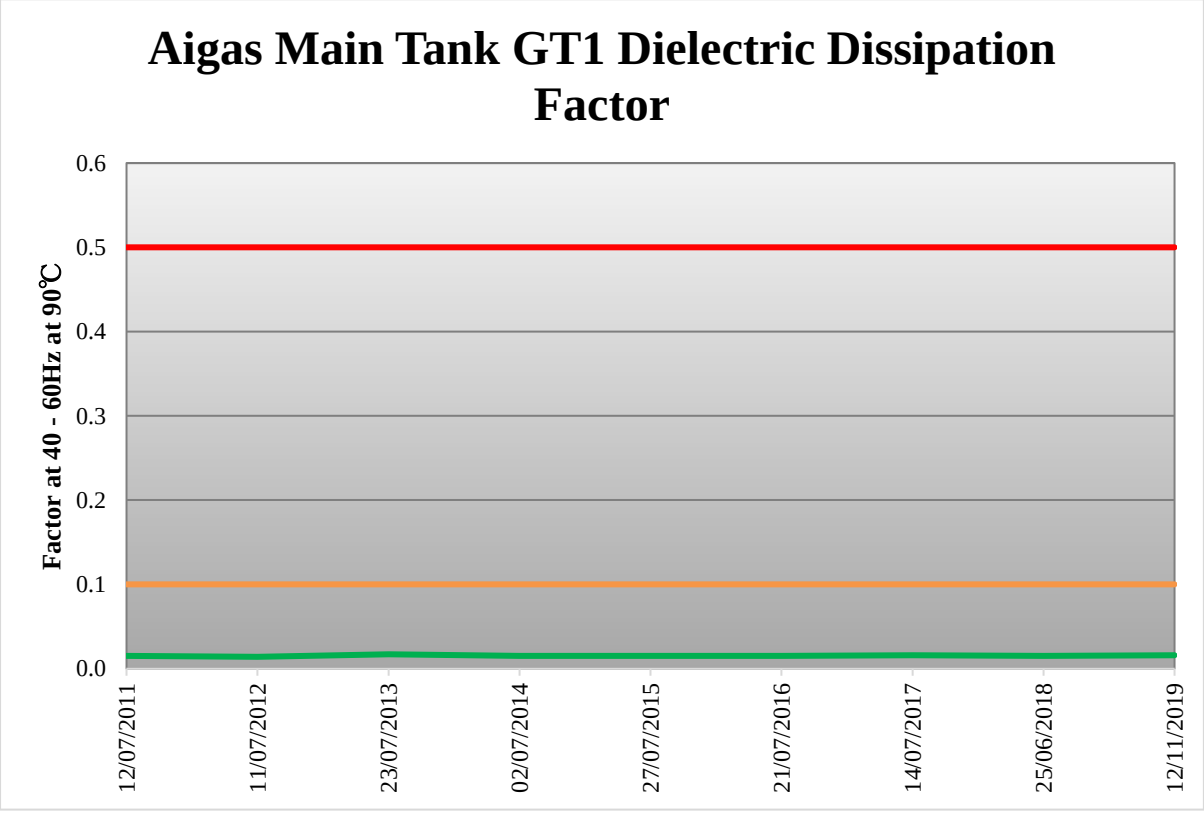


The selector historical breakdown voltage record spans the period of 2000 to 2018 and is inclusive of 21 samples. Except for samples from August 2008 (35kV), July 2011 (48kV) & July 2013 (50kV) categorised as "Fair", all breakdown voltage results are categorised as "Good" as defined in IEC 60422. Despite this overall categorisation, an erratic trend is displayed in the results. A clear correlation exists between reduced breakdown voltage results and an increased moisture content within the selector. Overall breakdown voltage results are satisfactory however, fluctuations in results suggest moisture management issues must be addressed.

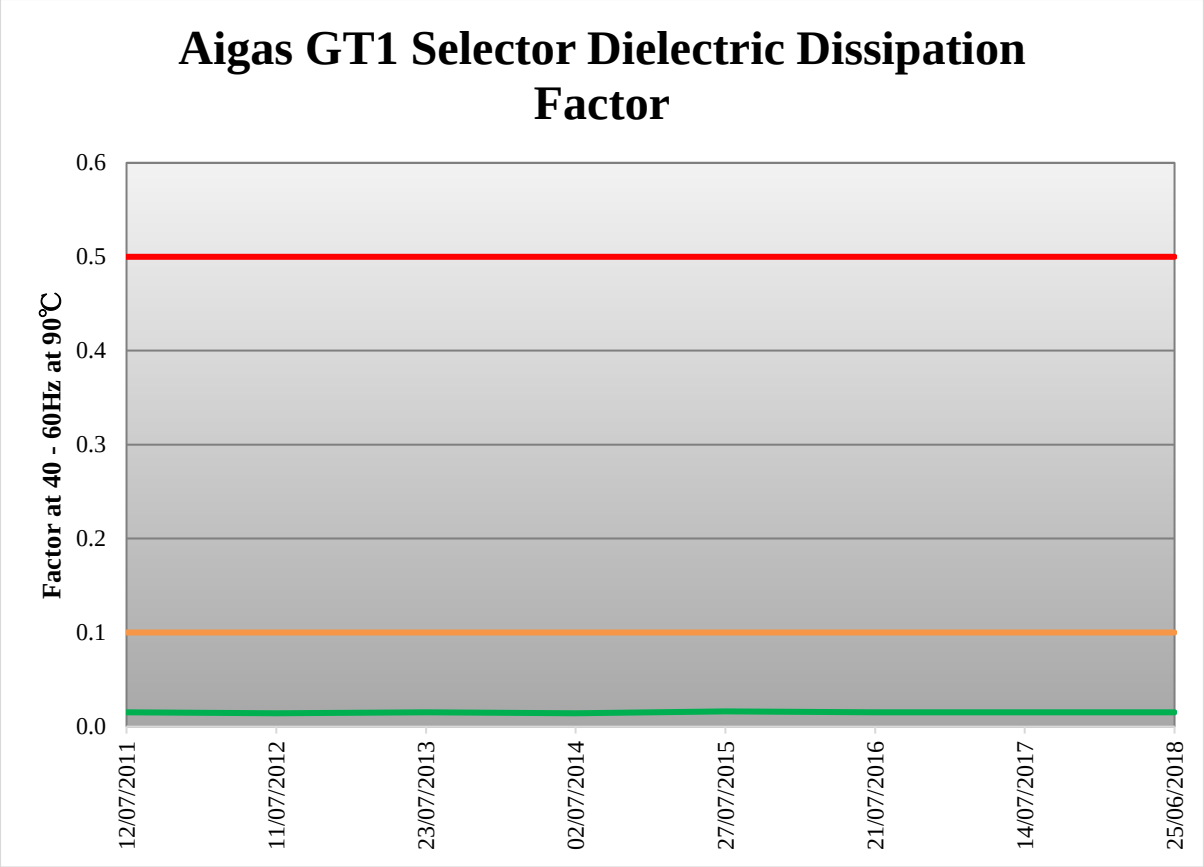
Dielectric Dissipation Factor

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**



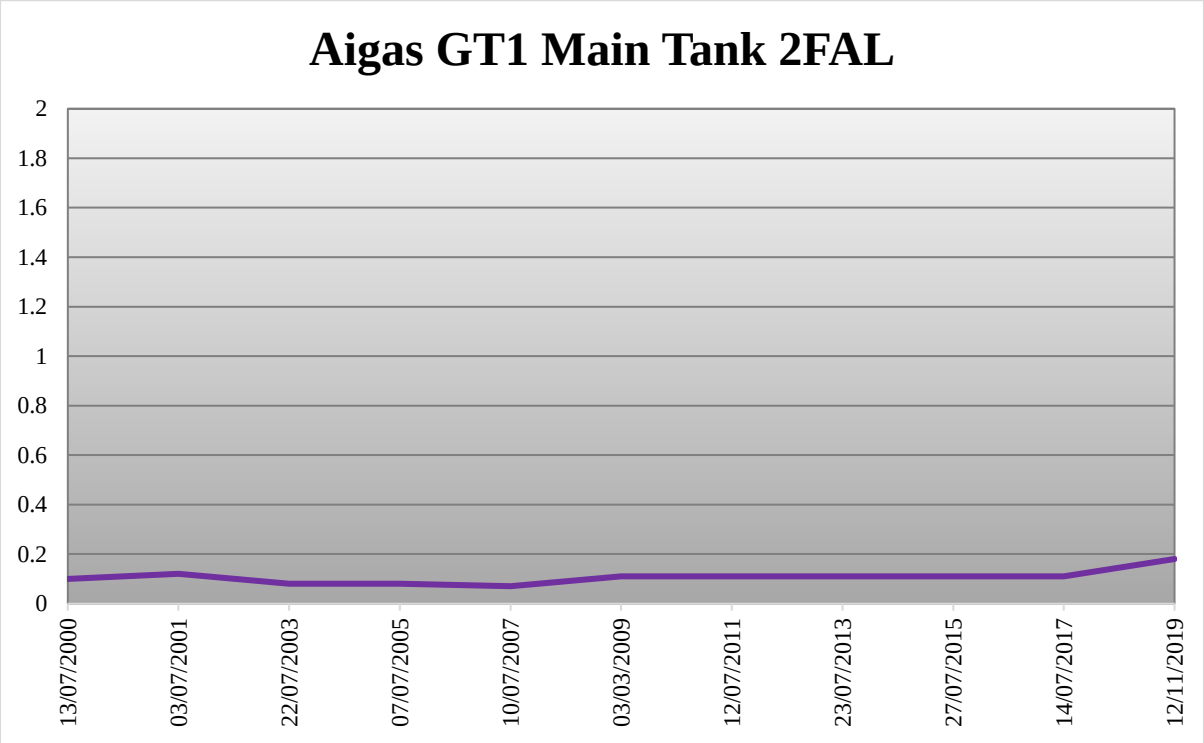
The dielectric dissipation factor is consistently categorised as "Good" as defined by IEC 60422. Results are satisfactory.



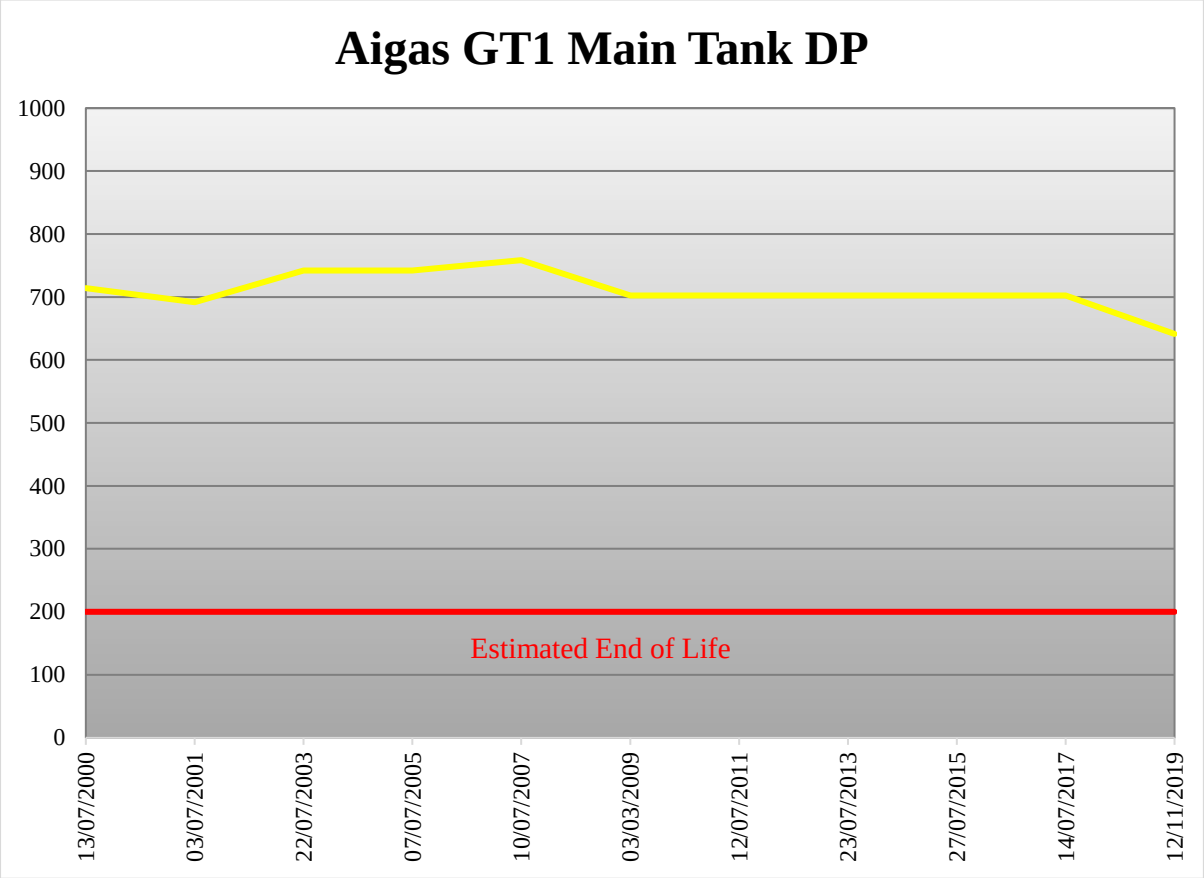
The dielectric dissipation factor is consistently categorised as “Good” as defined by IEC 60422. Results are satisfactory.

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 November 2019. The 2FAL levels an almost stable trend over the sample period with small increases noted in 2001 and 2009 which is most likely an indication of dilution of 2FAL levels by means of oil top ups. The final value recorded was 0.18 (Est DP 641), and also represents the peak value over the 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 November 2019). 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 in good condition given its age.



This figure is considered to be optimistic as the 2FAL has been diluted and with the 2FAL level being used to estimate the DP of the paper insulation, the estimated DP is most likely lower than the predicted figure.

132kV Bushings

No data available.

General

This section is compiled by making reference to the information contained within SSEN Report T2BP-ACR-0020 Revision 1.1 dated October 2019, henceforth referred to as the document.

Previous Condition Assessments

Previous condition assessments have highlighted various issues with GT1 general condition such as "Silica gel requires repositioning", "Oil absorbent material requires replacing" & "Oil leak from coolers" etc. Oil leaks have clearly been present for a prolonged period and supporting photos contained in the document substantiate this assessment, additionally the condition is anticipated to have deteriorated further since the date photographs were taken. As stated in the document, until 2017 Aigas maintenance was carried out by SSE Renewables and as such minimal iSIM data is available. Additional information states "Security inspections regularly note site is not well looked after". Quarterly inspections also note excessive "pigeon droppings" have made access unattainable and visible leaks from GT1 are observed. Oil weeping from high level pipework & conservator have been observed as well as substantial volumes of oil having been absorbed by pads located within the bund.

There is clearly active oil leaks on GT1 that require to be fully assessed. Given that the transformer is located in close proximity to the River Beauly, the transformer should be considered as an environmental hazard until such times as the oil leaks have been assessed and either repaired or the transformer has been replaced.

Partial Discharge Survey

The document reports that a partial discharge survey was conducted in August 2016 by Elimpus (Report: ELI-AIGA1-1601), with no indication of partial discharge being found. There is no evidence of partial discharge in transformer GT1 as concluded from DGA.

Infra-Red Thermovision Survey

An infra-red thermovision survey was conducted in December 2015 May 2016 with no abnormalities being found.

Impulse Protection

Unknown.

Load & Duty Cycle

No load or duty cycle data was provided for GT1.

Historical Faults

No historical fault data provided for GT1.

Maintenance

Until 2017 maintenance was carried out under contract by SSE Renewables. Therefore, historical maintenance records have not been possible to source. It would be advantageous to source maintenance records for GT1 & all associated apparatus to allow a detailed analysis of the assets condition. Limited information sourced from report TR-AIGA-058 details an inspection in 1997 was conducted when it was discovered oil was leaking from the main tank into the selector. This occurred due to degradation of the main tank flange, gasket & barrier panel. New gaskets are recorded as having been installed and new NBC gaskets were installed where necessary. It was believed these remedial actions were successful.

Conclusion

There are active oil leaks on GT1, which are currently being managed by the deployment of oil absorbent pads. The extent of the oil leakage require to be fully assessed. Given that the transformer is located in close proximity to the River Beauly, the transformer should be considered as an environmental hazard until such times as the oil leaks have been assessed.

The DGA does not exhibit any evidence of partial discharge or discharge abnormality, however there is a trend of dissolved ethylene, which is indicative of a thermal abnormality, which is low level at this stage but has been present throughout the DGA history. Assuming that the main tank and tap changer are communicating there is a degree of equilibrium between the main tank and tap changer dissolved ethylene levels. To identify of the source of the dissolved ethylene electrical testing would be required. Whilst these magnitudes of dissolved gases are still at low level, the dissolved ethylene should be kept under surveillance, in order to check for further manifestation on what could become degenerative thermal abnormality.

The oil quality parameters for the main tank 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. The tap changer moisture levels are more erratic than the main tank with frequent excursions into the "Fair" category as defined by IEC 60422:2013. The tap changer moisture management system requires to be checked for functionality and effectiveness.

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 in good condition given its age. The accuracy of 2FAL for use in "end of life" evaluation may be compromised due to the fact that the main tank oil has undergone processing in the past, as a means of improving the oil quality. Processing can remove 2FAL from the oil and can present as an over optimistic estimated DP.

It would therefore be advantageous to ascertain how often the transformer oil has been topped up. It is assumed that with an active oil leak(s) the oil system would require to be topped up, a practice which dilutes the oil quality indicators measured in the analysis of the oil.

There was no information available on the condition assessment of the 132kV bushings. There is no information on the load flow or duty cycle experienced by the transformer.

Access to the transformer maybe inhibited by the presence of bird excrement which presents a health and safety risk.

This transformer is internally in "reasonable condition" but has an underlying thermal abnormality and will require monitoring in the form of increased oil surveillance and may require enhanced maintenance within this period to prevent deterioration that may lead to failure. The external condition is aged. The transformer has active oil leaks. A 'mid-life' refurbishment should be considered in order to return the asset to a condition such that it will extend the asset life.

Recommendations

In order to mitigate the risk of an increased likelihood of failure during the RIIO T2 period and to understand the scope of work for a "mid-life" refurbishment, the following recommendations are made:

- Frequency of oil sampling should be increased to monitor dissolved ethylene, moisture content and dielectric breakdown voltage. This should be done every 6 months.
- The transformer will require to be cleaned down to mitigate the health and safety risk from bird droppings to facilitate a detailed inspection.
- Detailed inspection of the asset – outage required – to identify the source of the oil leaks.
- Inspection and assessment of the moisture management system.
- 132kV bushings should be oil sampled for DGA and moisture analysis and assessed by the criteria set out in National Grid TGN 82. In addition the bushing power factor and capacitance should be measured. This would require an outage and the removal of the 132kV and 11kV bushings to facilitate the testing.
- Detailed condition assessment of the transformer to include Sweep Frequency Response Analysis (SFRA), Dielectric Frequency Response (DFR), 10kV Power Factor, 5kV Insulation Resistance and DC Winding Resistance testing. This would require an outage and the removal of the 132kV and 11kV bushings to facilitate the testing.
- Following detailed inspection continue with routine inspection.
- Continue with routine maintenance.
- Detailed load flow monitoring.