Culligran GT1 132/11kV Transformer

Level 1 Condition Assessment Report 16th July 2020 Report: CULLGT1SHET200629 FINAL

Ian B B Hunter

Polaris
Diagnostics & Engineering Ltd

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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 Culligran 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-0024, 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 contamination of the main tank oil. 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 immediate action, as defined by the iSIM system. Additional inspection and evaluation is required. The transformer is wet, as evidenced by a very erratic main tank moisture levels and despite the oil being reconditioned and regenerated, the moisture levels return to what is considered high levels. This suggests that there is either moisture ingress into the main tank, or the active part insulation is wet. Oil processing 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 43% life remaining is considered optimistic.

This transformer is internally in "reasonable condition" but has a potential underlying thermal abnormality, which could manifest into a more serious deterioration. The transformer is wet and has a history of oil leakage. The main tank oil 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. 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 both dissolved ethylene and moisture content and dielectric breakdown voltage. This should be done every 6 months with additional oil analysis (over and above routine measurements).
- Detailed inspection of the asset – outage required.
- 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	Editorial & 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 Culligran 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 02/X/256

This transformer was manufactured in 1962, and was installed and commissioned at Culligran 132kV substation.

Electrical Plant Details

Manufacturer:	Bonar Long
Serial Number:	02/X/256
Year of Manufacture:	1962
ON/OFB Rating:	25 MVA
Ratio:	132/11 kV
Vector Group:	Unknown
Impedance:	Unknown
Tap Changer Manufacturer:	AEI
Tap changer Type:	TC M54E42
Tap Changer Serial Number:	T602470
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

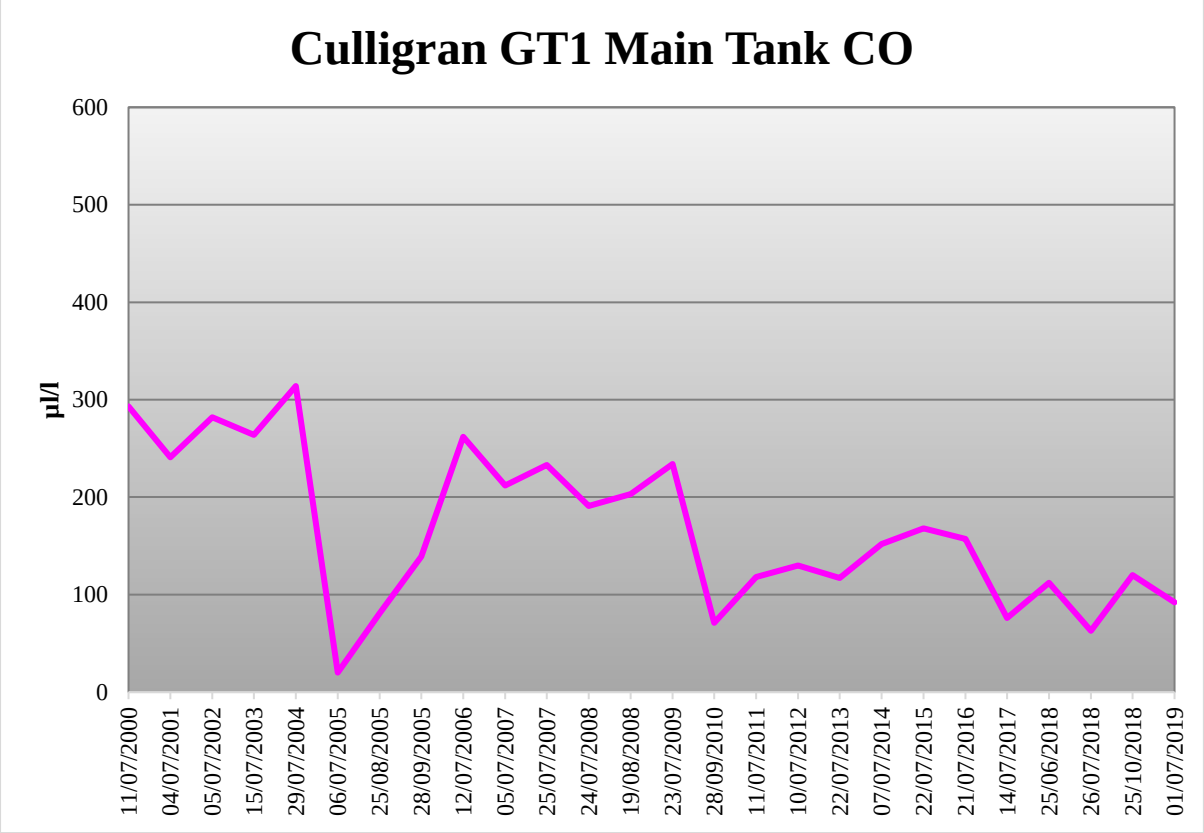
Main Tank Oil History

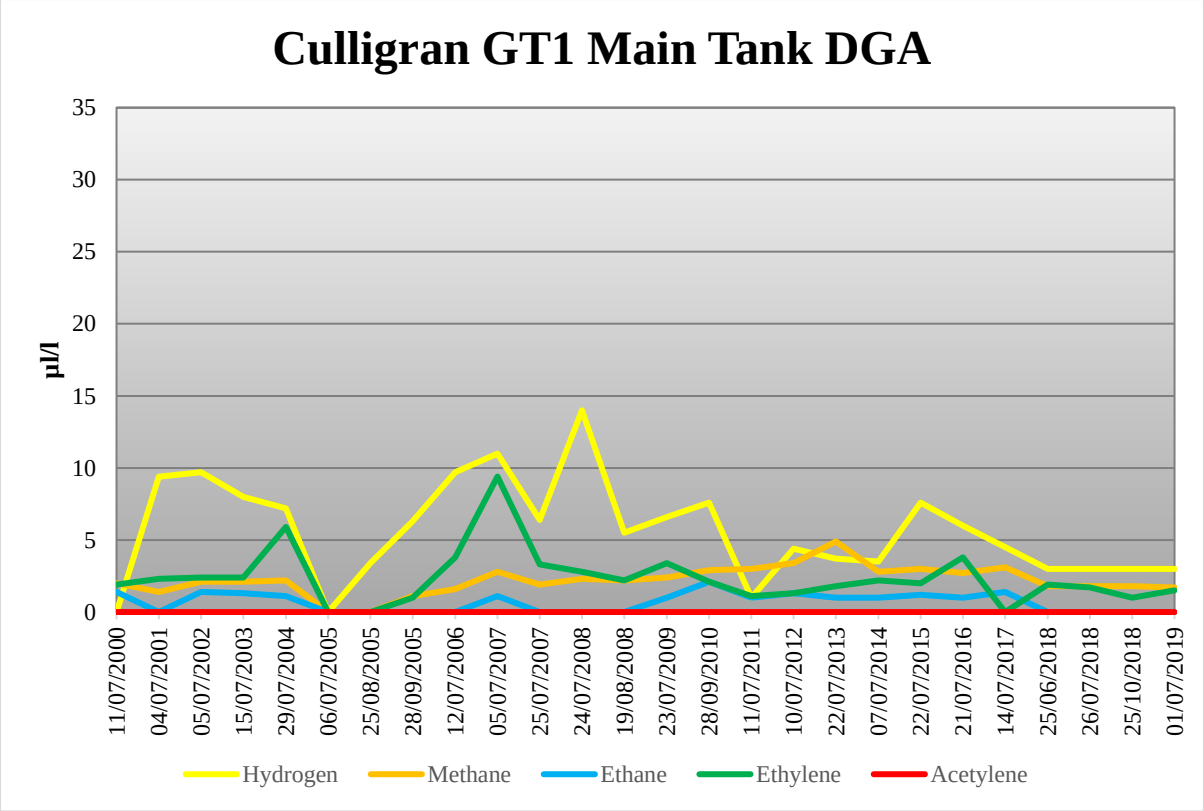
Dissolved Gas Analysis – Main Tank History

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 1900 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 has spikes, indicating periods of ageing but overall, exhibits a decreasing trend. All values remain below "typical values" specified in IEC 60599 over the sample period, peaking at 314µl/l in 2002. The paper insulation is likely in reasonable condition for its age.





Thermal gases Methane, Ethane & Ethylene are present throughout the DGA history however, all remain at levels well below "typical values" specified in IEC 60599. There are two identifiable peaks in dissolved ethylene which have not manifested into a more serious underlying thermal condition.

Application of the gas ratios, as defined in IEC 60599, [0,0.66,undefined] fails to highlight a fault condition through a diagnosis of 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 presently considered to be too low to accurately diagnose and in this case the DGA would be considered benign.

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

Thermal Events:

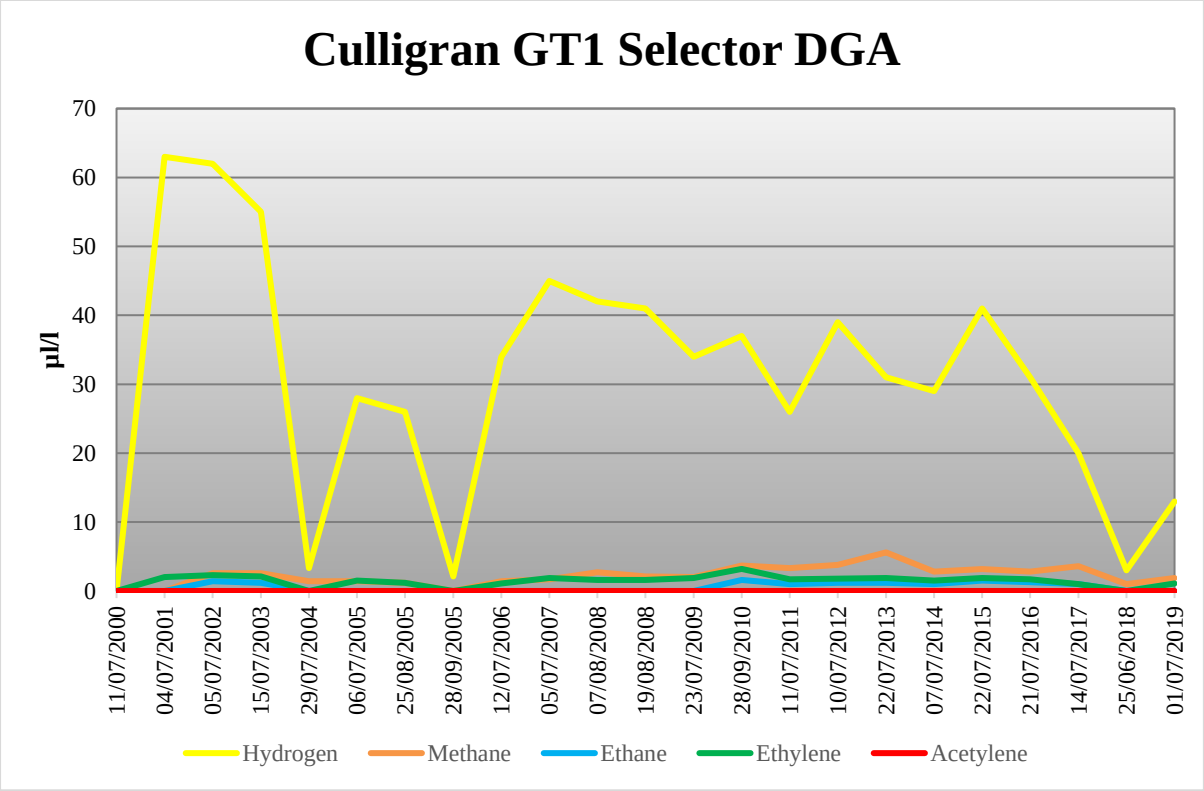
None

Discharge Events:

None

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".



Thermal gases Methane, Ethane & Ethylene are present throughout the DGA history however, all remain at levels well below "typical values" specified in IEC 60599. The key gas present is Hydrogen which is still at low level.

Application of the gas ratios, as defined in IEC 60599, [0,0.15,undefined] fails to highlight a fault condition through a diagnosis of non-classification diagnosis. 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, which is 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 presently exhibit any evidence of partial discharge, discharge, or thermal abnormality. The DGA history can be described as benign.

Thermal Events:

None

Discharge Events:

None

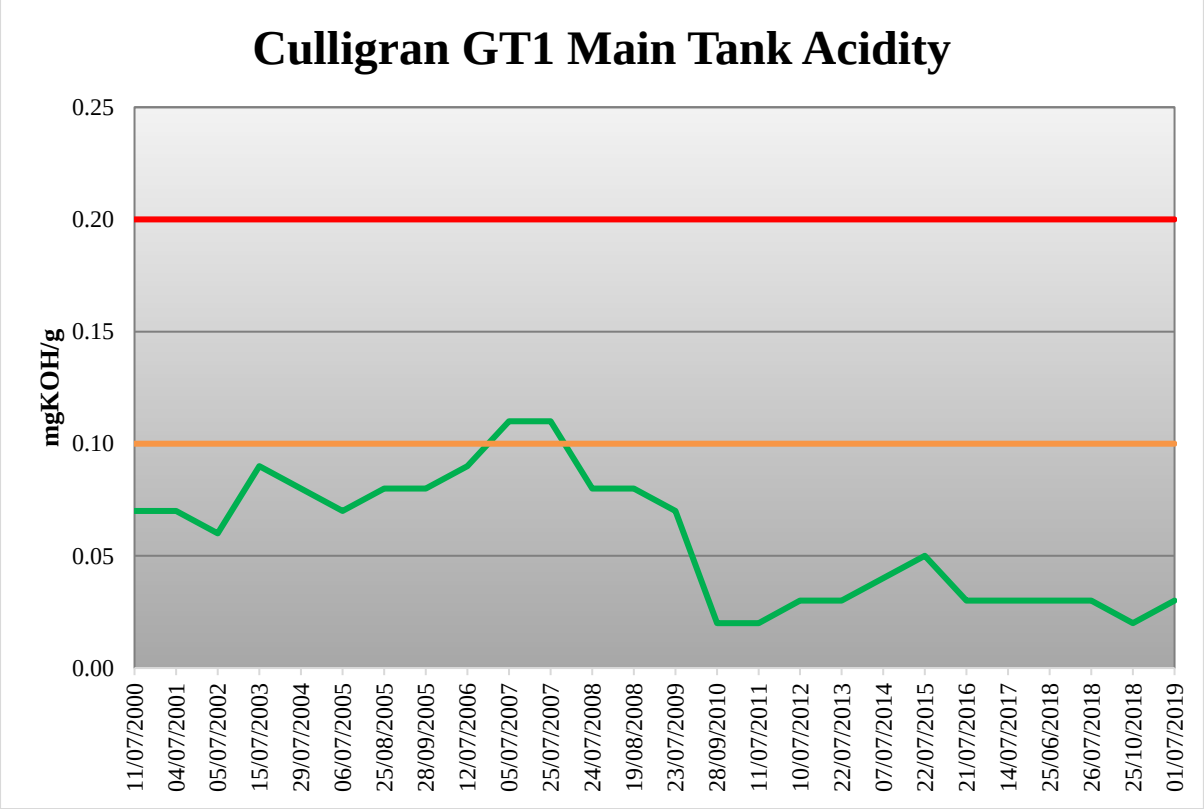
Main Tank Oil Quality Analysis

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."* As this transformer has a primary voltage of 132kV, it falls into the "Category B" limits as defined in the standard.

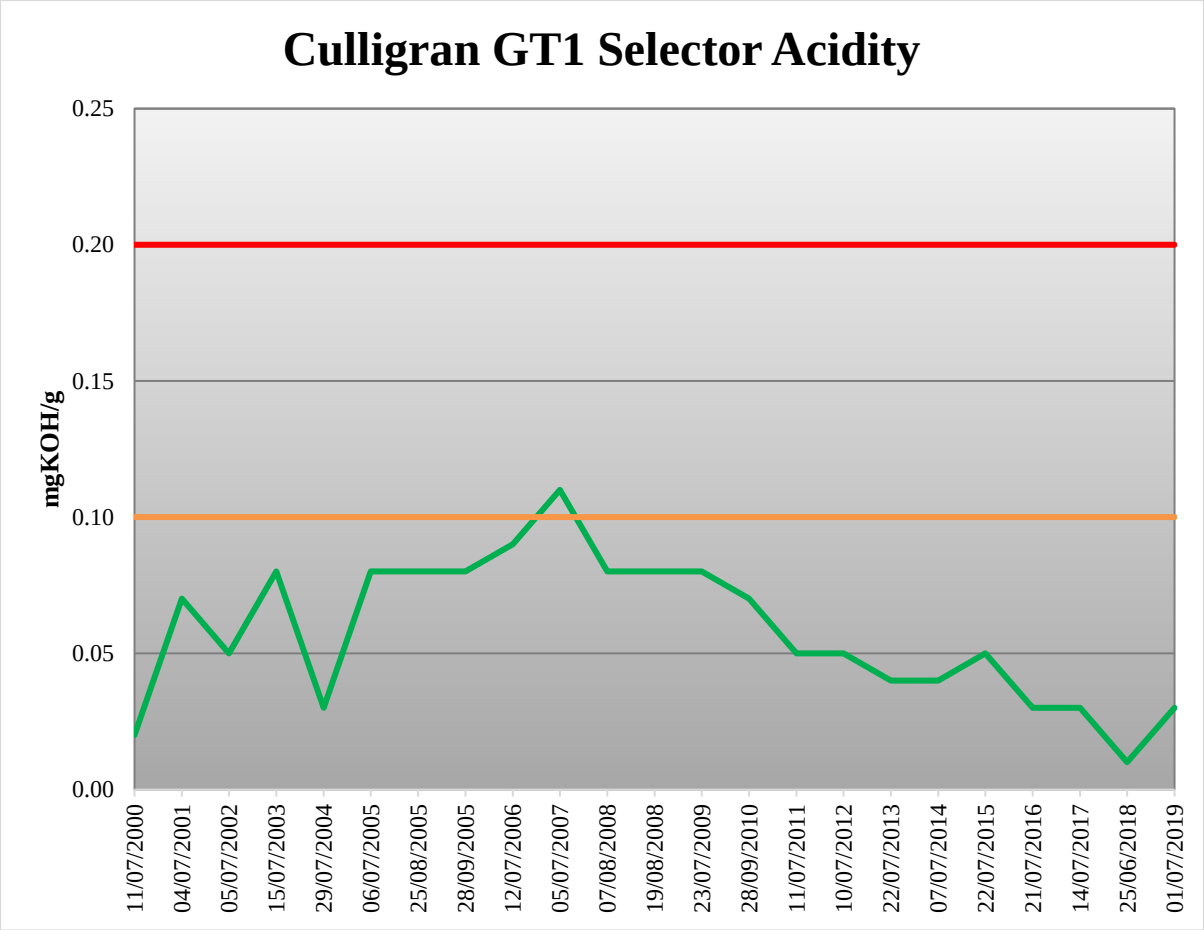
Acidity

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 26 samples taken in the period of 2000 to 2019. The acidity levels between July 2000 & July 2007 clearly indicate an increasing trend indicative of oxidisation of the oil. From 2007 onwards an overall decreasing trend is observed most likely the result of top ups to the main tank oil or an intervention in the oil system. Except for two sample from July 2007 which are categorised as "Fair" by IEC 60422, all samples are categorised as "Good". The most recent acidity result of 0.03 which is satisfactory and considered representative of recent historical results.

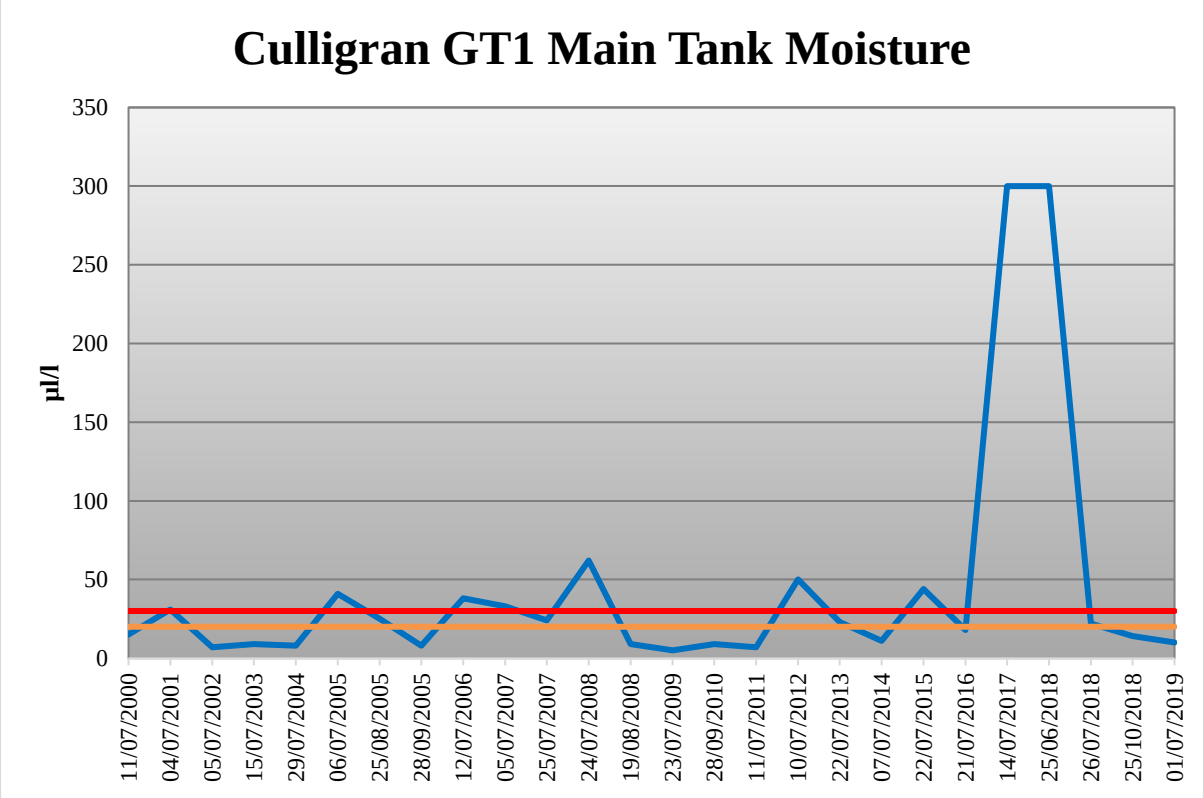


The historical acidity record spans the period of 2000 to 2019 and includes 23 samples. The acidity levels are observed to from 2007 onwards indicative of a dilution effect to the main tank oil by means of oil top ups or an intervention been carried out on the oils system. Being a tap changer this may be due to sympathetic communication from the main tank oil. Acidity levels are consistently categorised as "Good" as defined by IEC 60422, with the exception of one sample from July 2007 (0.11) which is categorised as "Fair". The most recent acidity result of 0.03 is classified as "Good" and considered to be satisfactory representative of recent historical results.

Moisture

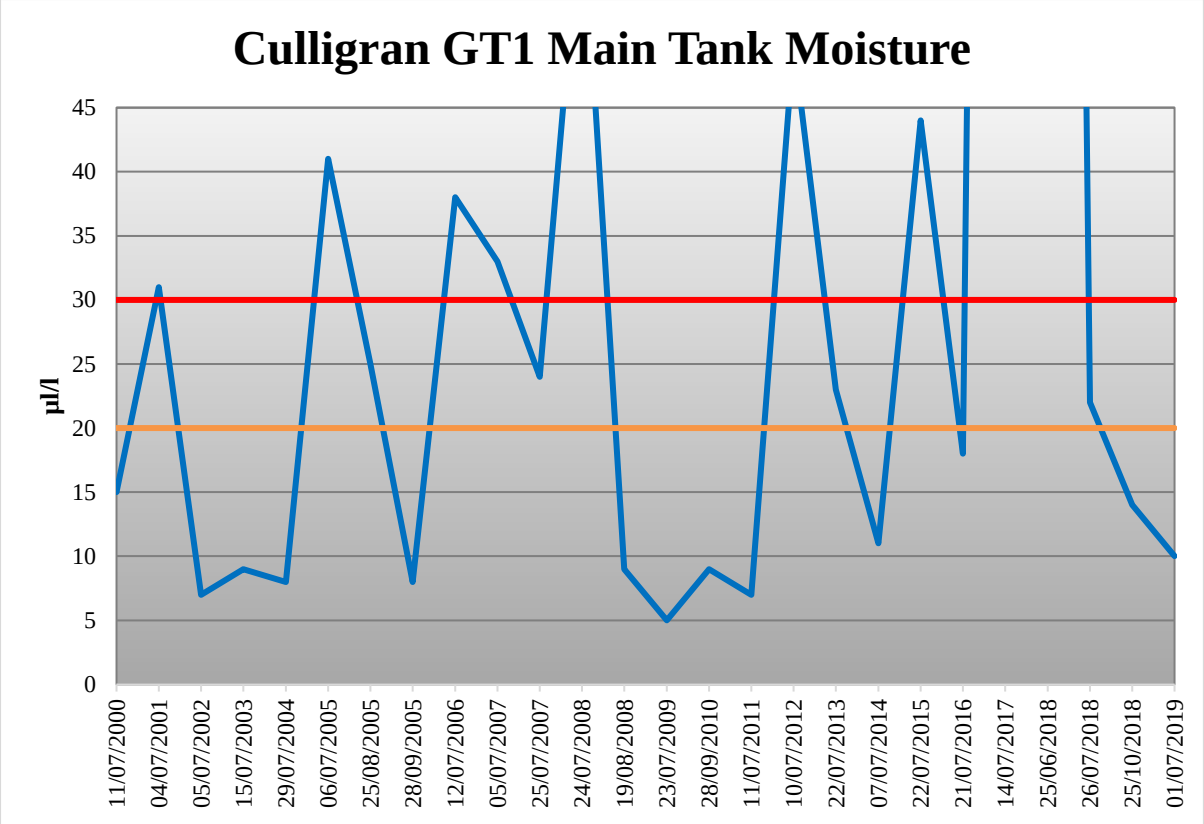
The moisture level influences the breakdown voltage of the oil, the solid insulation and affects the ageing characteristics of the liquid and solid insulation. There are two main sources of water, ingress from atmosphere and from the degradation of cellulose in oil.

IEC 60422 "Category B" Limits for Moisture	
Classification	**µl/l**
Good	**< 20**
Fair	**20 -30**
Poor	**> 30**

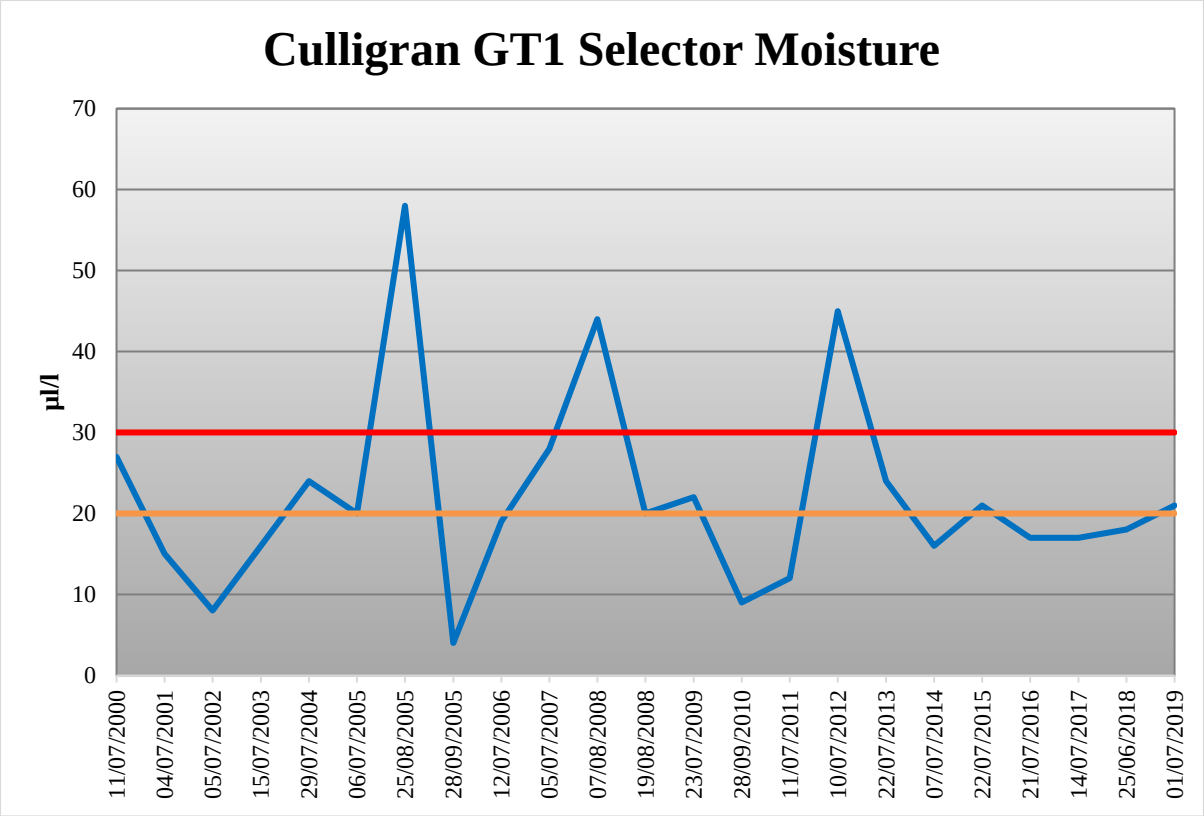


The historical moisture records contain two samples dated July 2017 & June 2018 where moisture levels are recorded as 300µl/l. Report T2BP-ACR-0024 states remedial works were conducted on GT1 to address oil leak issues. The high moisture content is believed to have been caused by voids in steelwork and seals of the transformer.

The moisture trend has been re-graphed to assess the operating levels of moisture, removing the very large abnormal peaks – for clarity.



The historical moisture data spans 26 samples taken in the period of 2000 to 2019. Over the sample range the moisture levels have exhibited an erratic characteristic, likely due to the oil leak issues. Report T2BP-ACR-0024 states "Oil was reconditioned in February 2010", if this is accurate it appears to have made no respectable difference to moisture content of GT1 as moisture levels continue to rise post – reconditioning. Moisture content consistently fluctuates between values categorised as "Good"; "Fair" & "Poor" as defined by IEC 60422 for category B apparatus. The most recent moisture result of 10µl/l is categorised as "Good" but is not considered representative of historical moisture results.

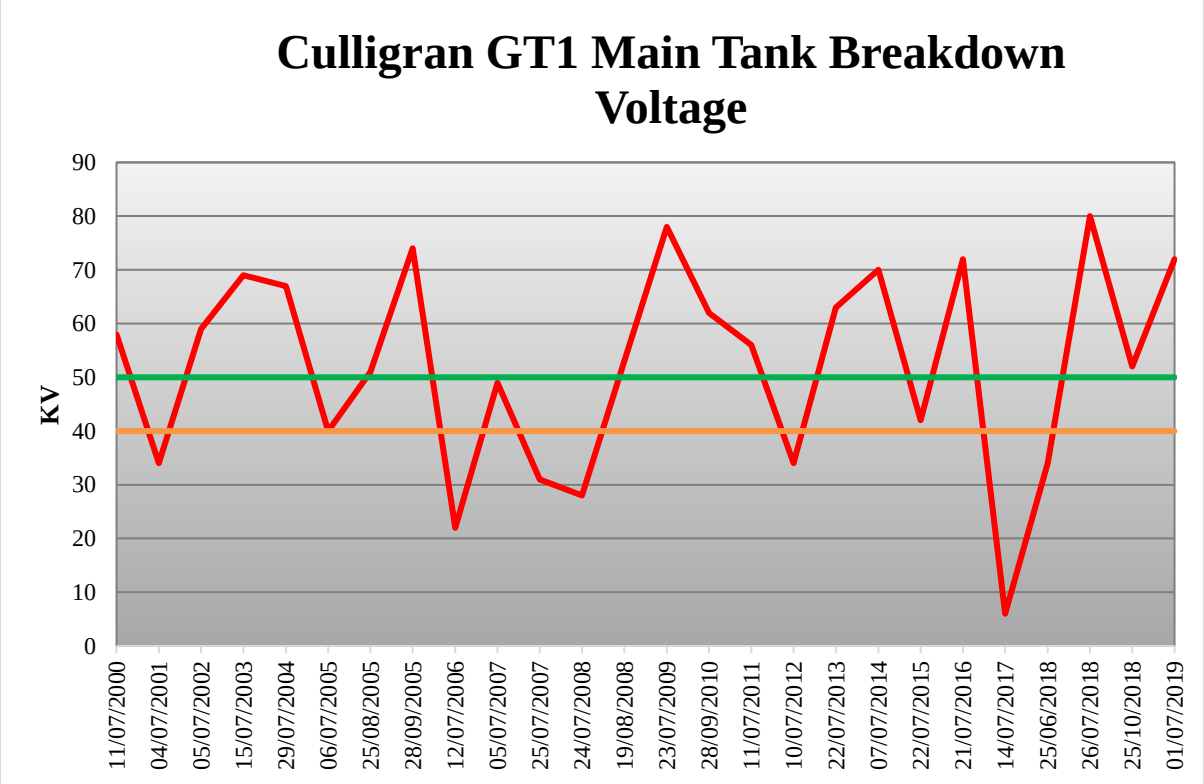


The historical selector moisture data spans 23 samples over the period of 2000 to 2019. Over the operational life of the selector moisture levels have been dynamic, this has resulted in a fluctuation between a categorisation of "Good", "Fair" & "Poor", as defined by IEC 60422. Correlation in increased moisture in the selector & the main tank are observed in August 2005, August 2008 & July 2012. This would suggest that moisture management of the main tank should be improved and because of this action, selector moisture levels should also reduce. Communication between the main tank and selector moisture levels is evident. Peak moisture value in the selector is recorded as 58µl/l in August 2005. The moisture trend is not satisfactory.

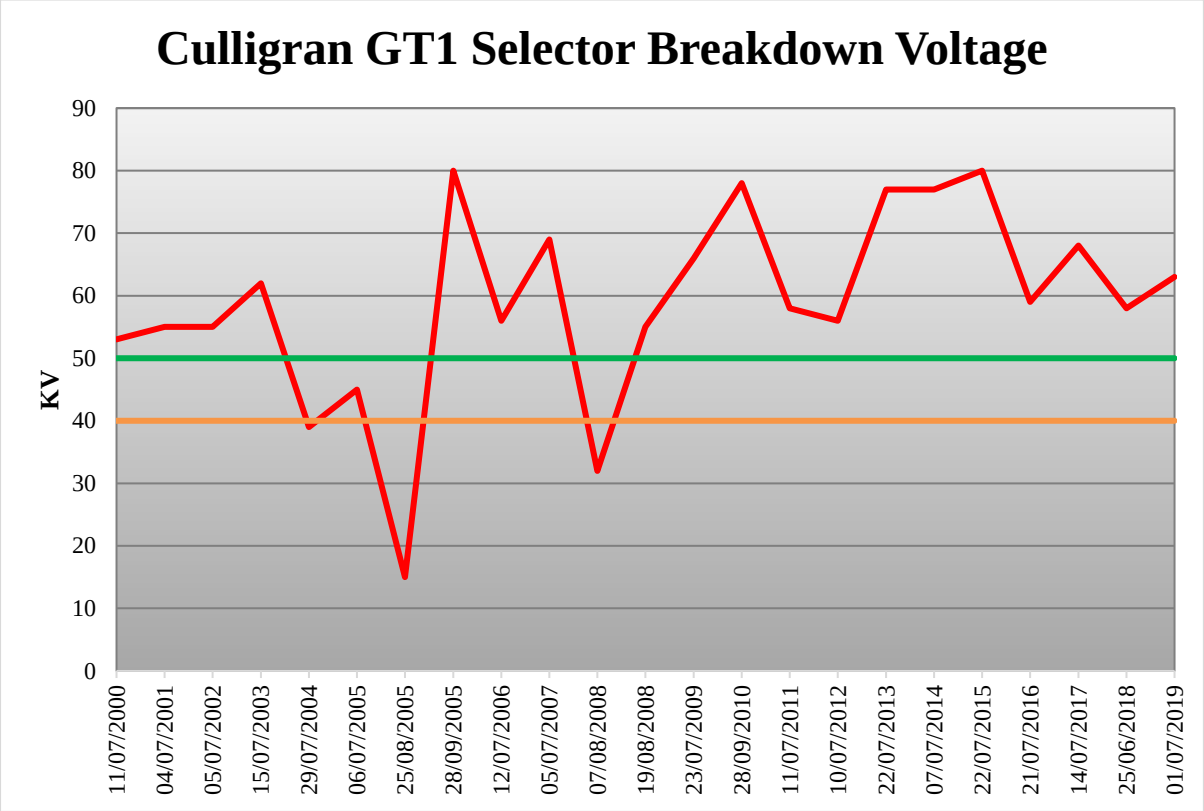
Breakdown Voltage

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 the period of 2000 to 2019 and is inclusive of 26 samples. The breakdown voltage levels present an erratic trend which can be categorised as "Good", "Fair" and "Poor" as defined by IEC 60422 throughout the historical range. All major reductions in breakdown voltage levels correlate with increased moisture content in the main tank. The most recent result from July 2019 (72kV) is categorised as "Good" but is not representative of the historical sample range. Remedial actions are clearly required to improve moisture management of GT1.

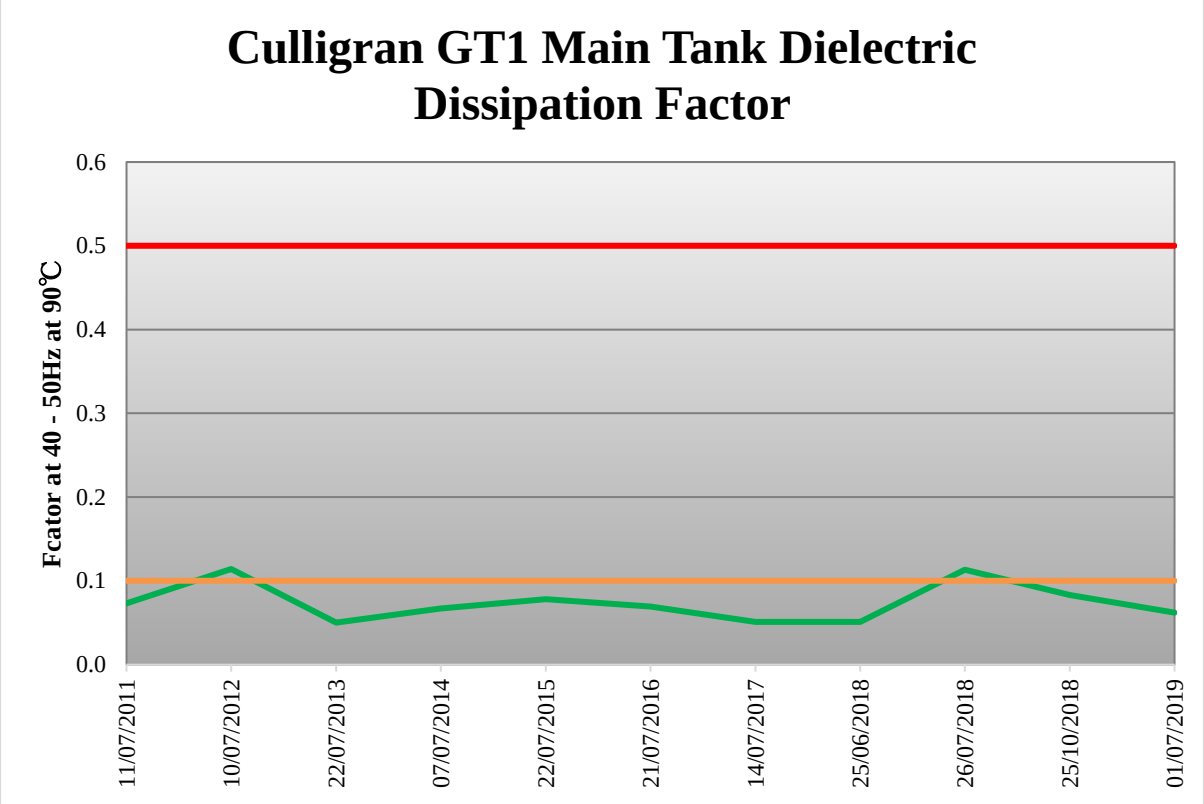


The selector historical breakdown voltage record spans the period of 2000 to 2010 and is inclusive of 23 samples. The breakdown voltage levels present an erratic trend which can be categorised as "Good", "Fair" and "Poor" as defined by IEC 60422 throughout the historical range. A clear correlation exists between reduced breakdown voltage results and an increased moisture content within the selector in July 2005, August 2008 & July 2012. Present breakdown voltage results are satisfactory however, historical fluctuations in results suggest moisture management issues must be addressed.

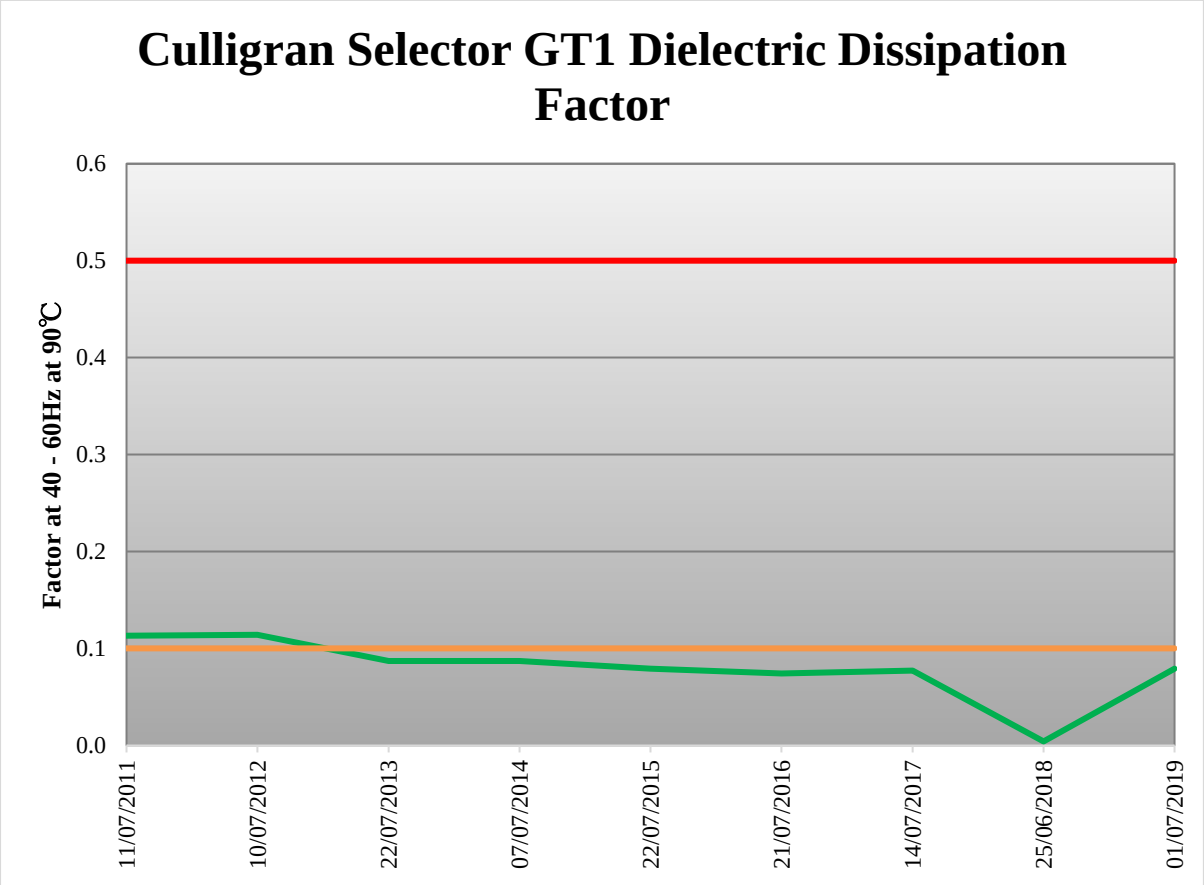
Dielectric Dissipation Factor

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**



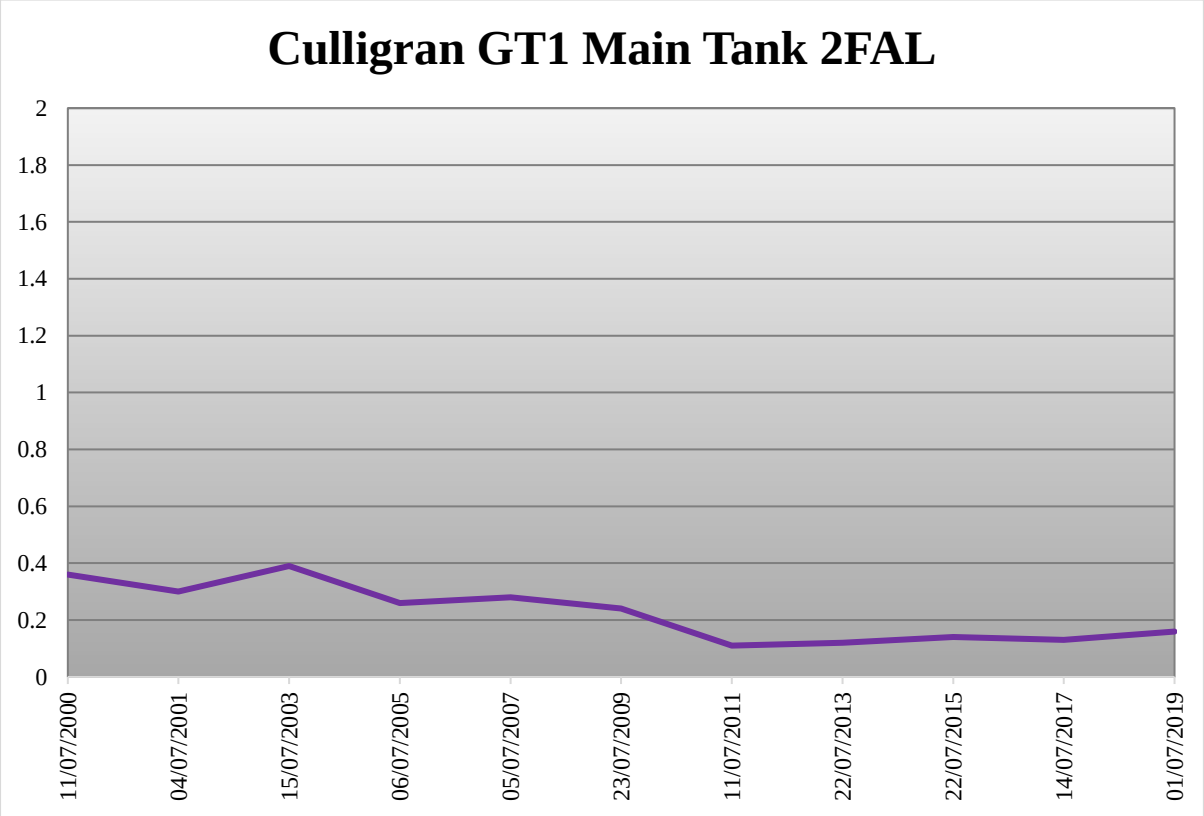
The Dielectric dissipation factor historical results contain 11 results in the period of 2011 to 2019. With the exception of samples taken in July 2012 (0.114) & July 2018 (0.113) both categorised as "Fair" by IEC 60422, all results are categorised as "Good". A trend is observed which suggests dilution of the main tank oil by means of top ups or oil interventions. The present results are considered satisfactory and fairly representative of the DDF history.



The dielectric dissipation factor is predominantly categorised as "Good" as defined by IEC 60422. Reductions in dielectric dissipation factor results are indicative of a dilution effect by means of top ups with new or reclaimed oil or an intervention in the oil system has taken place. Results are satisfactory.

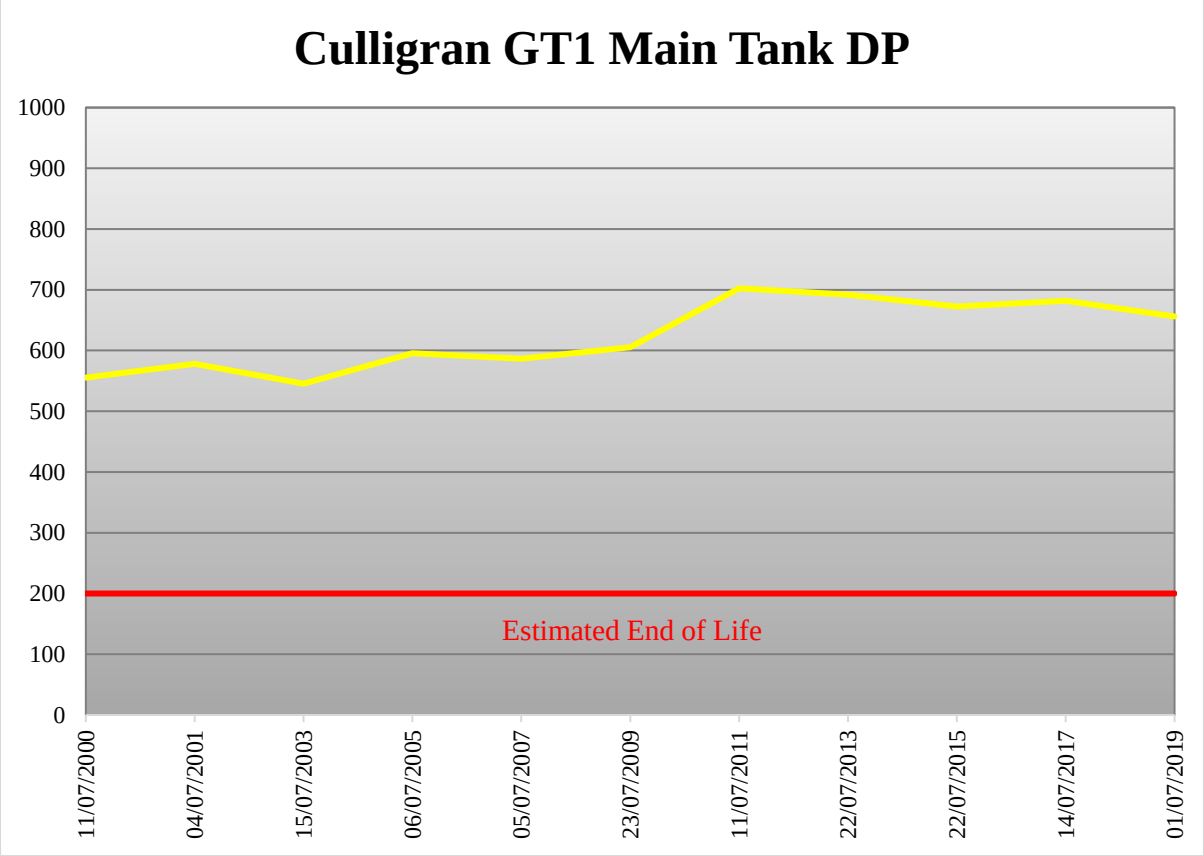
2FAL

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 July 2017. The 2FAL levels show an overall decreasing trend between July 200 & July 2011. This is indicative of a dilution of 2FAL levels by means of top ups with new or reclaimed oil, or an intervention having taken place in the oil system. The final value recorded was 0.16 (Est DP 656), compared to the highest value recorded in the sampling period of 0.39 (Est DP 545). 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 July 2003). Measured 2FAL

of 0.39 gives an estimated DP of 545. 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 43% residual life remaining in the paper insulation. This suggests that the paper insulation is in a 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 132kV bushing data was made available.

General

The following sections are made with reference to information contained within Report T2BP-ACR-0024, henceforth referred to as document.

Previous Condition Assessments

As mentioned in the document section 5.3.1 previous condition assessments have highlighted various issues with the general condition of GT1 such as several prominent oil leaks, voids in steelwork and seals of the transformer and an erratic moisture trend peaking at 300µl/l. Remedial work to repair void in steelwork & seals are noted as well as a reconditioning of the main tank oil in 2010 however, this appears to only have temporarily reduced issues associated with excess moisture content. Previous condition assessments have graded GT1 as requiring "Additional maintenance" and based upon historical oil analysis & photographic evidence contained within the document this assessment is deemed accurate. Transformer GT1 has an overall iSIM score of 3 which is detailed as significant deterioration.

Partial Discharge Survey

The document reports that a partial discharge survey was conducted in January 2017 by Elimpus (Report: Barry Cairns "CULLIGRAN 132kV AIS PD SURVEY) 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 with no abnormalities being found.

Impulse Protection

Unknown.

Load & Duty Cycle

No load or duty cycle data was provided for GT1.

Historical Faults

08/11/2017 – High oil alarm and blocked pump due to leaves. New bin, barrels, dirty pump and pressure washer required.

05/12/2018 – Oil leak from top of transformer.

06/04/2018 – Breather needs recharged.

Maintenance

As previously stated, until 2017 maintenance was carried out by SSE renewables until 2017. Maintenance details obtained from PLACAR are shown below.

GT1 - MW 132kV Grid Transformer Maintenance - 26/09/2002

GT1 TAP - MW 132kV Grid Transformer Tap changer maintenance - 26/09/2002

GT1 - MW 132kV Grid Transformer Maintenance - 09/06/2008

GT1 TAP - MW 132kV Grid Transformer Tap changer maintenance - 09/06/2008

GT1 - MW 132kV Grid Transformer Maintenance - 30/08/2010

GT1 TAP - MW 132kV Grid Transformer Tap changer maintenance - 30/08/2010

GT1 - MW 132kV Grid Transformer Maintenance - 06/09/2017

GT1 TAP - MW 132kV Grid Transformer Tap changer maintenance - 06/09/2017

Conclusion

Previous condition assessments have highlighted various issues with the general condition of GT1 such as several prominent oil leaks, voids in steelwork and seals of the transformer and an erratic moisture trend peaking at 300µl/l. Remedial work to repair a void in steelwork & seals are noted as well as a reconditioning of the main tank oil in 2010 however, this appears to only have temporarily reduced issues associated with excess moisture content. Previous condition assessments have graded GT1 as requiring "Additional maintenance" and based upon historical oil analysis & photographic evidence contained within the document this assessment is deemed accurate. Transformer GT1 has an overall iSIM score of 3 which is detailed as significant deterioration. With the reconditioning of the main tank oil, apparently only having a short term benefit, this would suggest that the transformer is wet, either the oil leaks have not been repaired, the solid insulation on the active part has a high moisture content or a combination of both.

The DGA does not presently exhibit any evidence of partial discharge, discharge, or thermal abnormality. There are two identifiable low level peaks in dissolved ethylene which have not manifested into a more serious underlying thermal condition.

The oil quality parameters for the main tank comprising of moisture, breakdown voltage, acidity and DDF are presently all categorised as "Good" as defined by IEC 60422:2013 indicating that the insulating oil has good dielectric properties. However, due to the erratic and poor nature of the historic oil quality values, it is considered that the transformer is wet and moisture could migrate from the solid insulation back into the oil system, thus compromising the dielectric properties of the oil. This should be kept under surveillance and may require intervention.

The oil quality parameters for the tap changer selector comprising of breakdown voltage, acidity and DDF are all categorised as "Good" as defined by IEC 60422:2013. The moisture is categorised as "Fair" as defined by IEC 60422:2013 but has a dynamic history due to migration from the main tank and possibly from oil leakage. This should be kept under surveillance and may require intervention.

Measured 2FAL of 0.39 gives an estimated DP of 545. 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 43% residual life remaining in the paper insulation. This suggests that the paper insulation is in a 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.

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.

This transformer is internally in "reasonable condition" and has a potential underlying thermal abnormality. The transformer is wet and has a history of oil leakage. The main tank oil 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. 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 both dissolved ethylene and moisture content and dielectric breakdown voltage. This should be done every 6 months with additional oil analysis (over and above routine measurements).
- Detailed inspection of the asset – outage required.
- 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.