Kilmorack GT1 132/11kV Transformer

Level 1 Condition Assessment Report 16th July 2020 Report: KILOGT1SHET200629 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 Kilmorack 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 SSEN Report T2BP-ACR-0021 Revision 1.1 dated October 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 low level 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.

The transformer having an estimated 56% residual life remaining in the paper insulation. This suggests that the paper insulation is in a good condition given its age.

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 and presents a significant environmental hazard. 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 v3	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 Kilmorack 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 40733

This transformer was manufactured in 1960 and was installed and commissioned at Kilmorack 132kV substation.

Electrical Plant Details

Manufacturer:	Bruce Peebles
Serial Number:	40733
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:	104163
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.

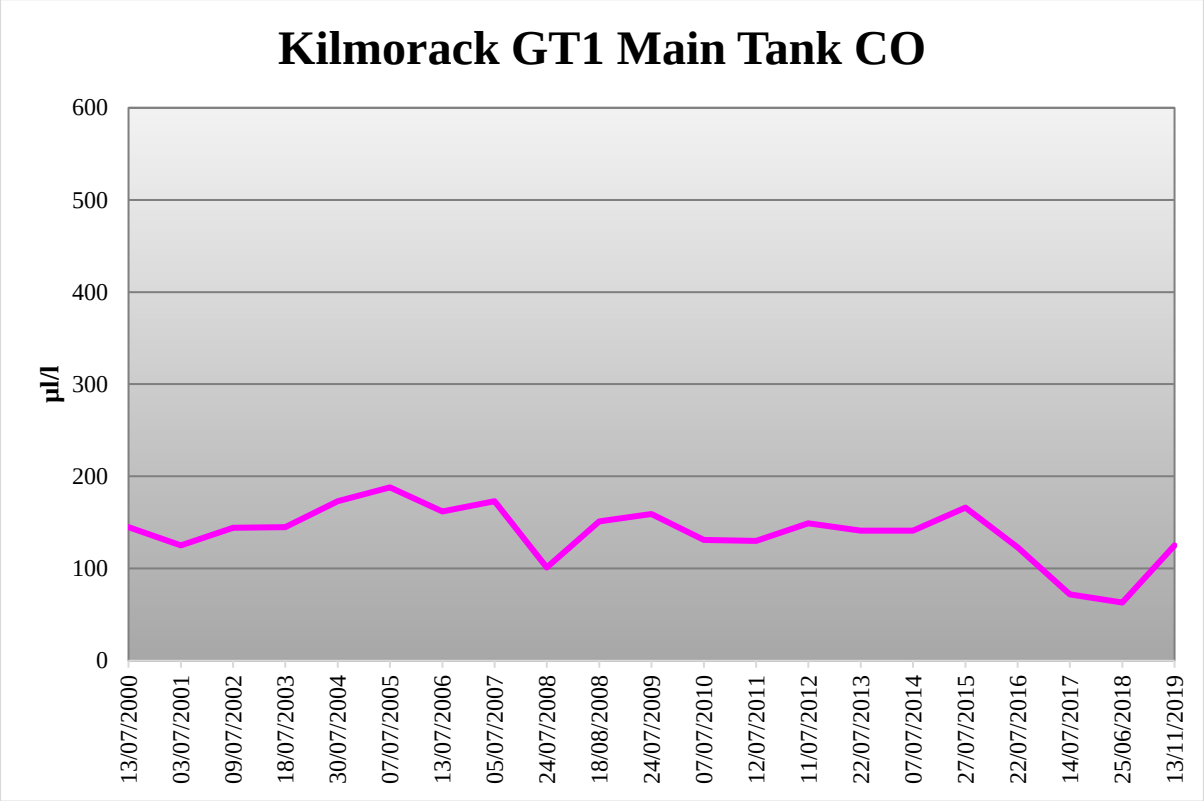
Main Tank Oil History

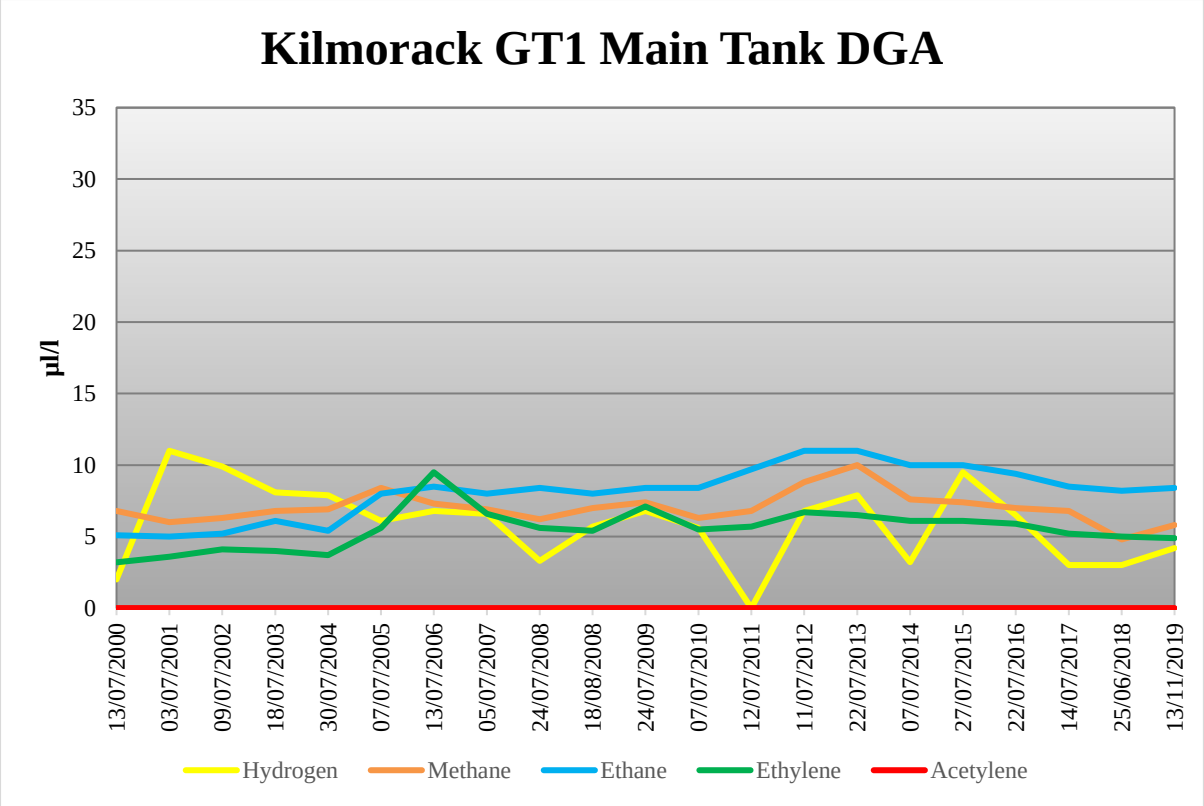
Dissolved Gas Analysis – Main Tank History

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 considered relatively stable and remains below "typical values" specified in IEC 60599 over the sample period, peaking at 188µl/l in 2005. 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, 1.5, 0.58] fails to highlight any abnormality 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 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, however the dissolved ethylene should be kept under surveillance.

Thermal Events:

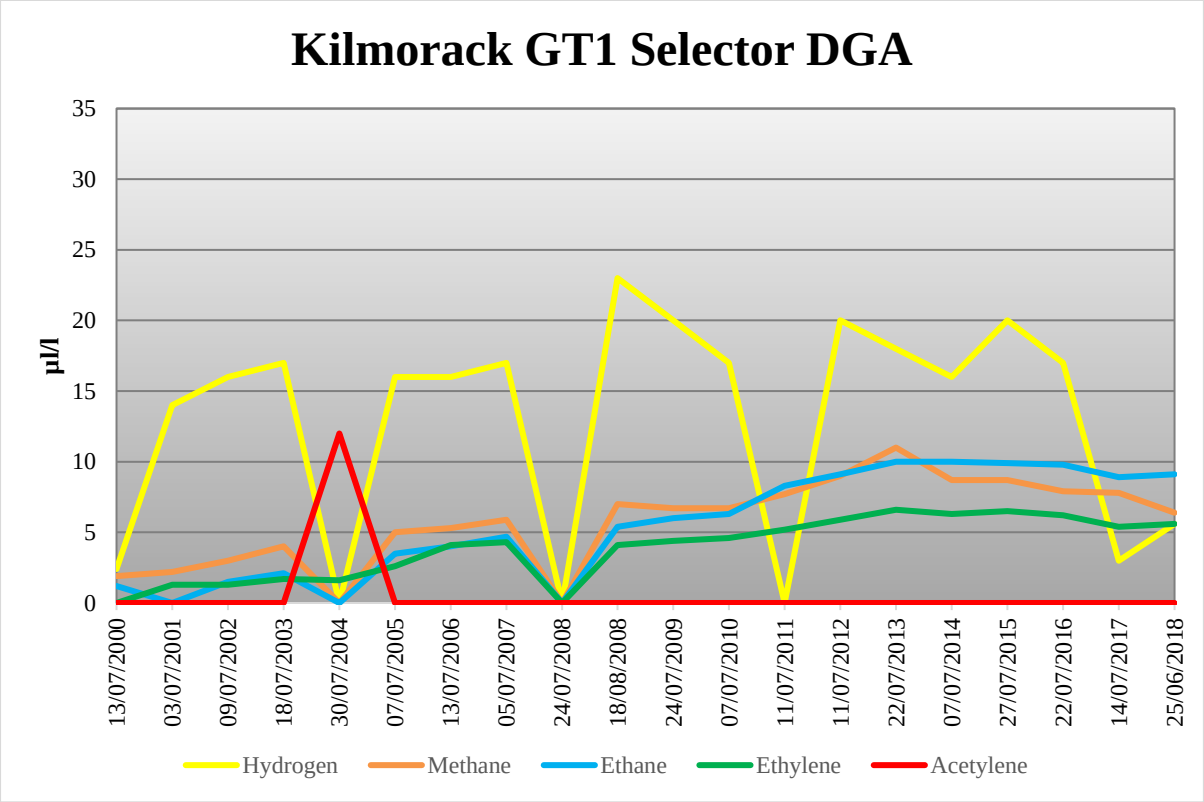
Note: Low level dissolved ethylene is present.

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 and Ethylene are all present in the DGA history, however, remain at low levels well below "typical values" specified in IEC 60599. Correlations in thermal gases are indicative of a potential high temperature thermal abnormality occurring at low levels. Also, the trend exhibited by thermal gases correlates with the trend displayed in the main tank DGA analysis which confirm communication between the main tank and the selector. Interventions have taken place in 2004 and 2008.

Application of the gas ratios, as defined in IEC 60599, [0.0, 1.0, 0.61] fails to highlight any abnormality 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 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, however the dissolved ethylene should be kept under surveillance.

Thermal Events:

Note: Low level dissolved ethylene is present.

Discharge Events:

None

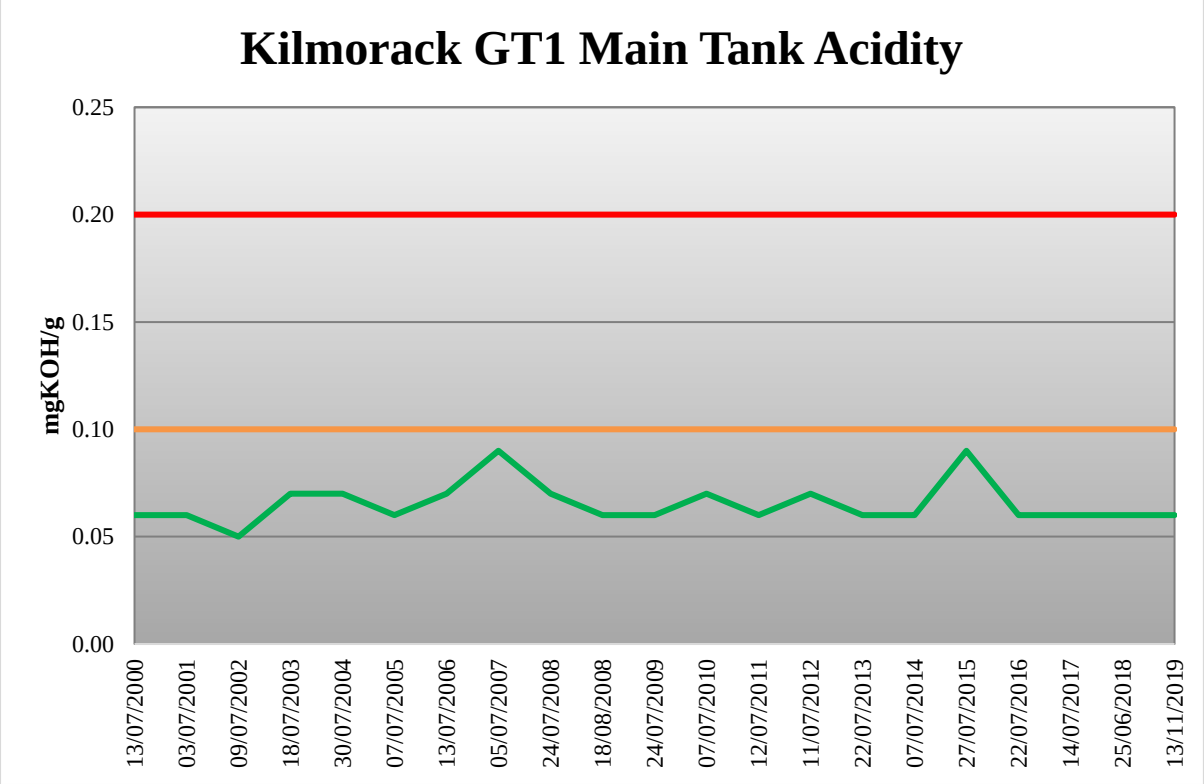
Main Tank Oil Quality Analysis

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.

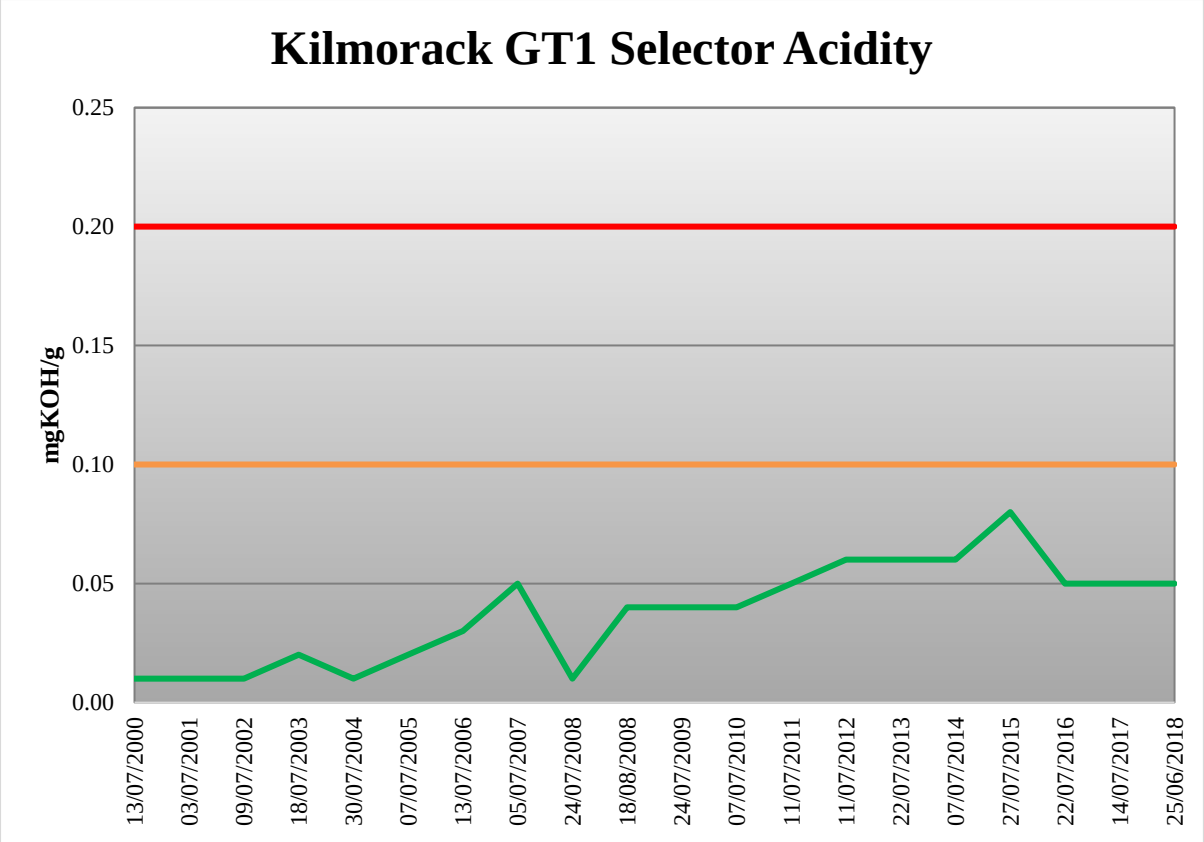
Acidity

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 contains 21 samples taken in the period of 2000 to 2019. The acidity levels are found to be relatively stable however, short periods of increased acidity content are indicative of oxidisation of the main tank oil. Also, minor reductions observed are indicative of dilution by means of top ups to the main tank with new or reclaimed oil or an intervention. Over the sample range all results are consistently categorised as "Good" as defined by IEC 60422 for category B apparatus. Overall, the acidity is considered satisfactory.

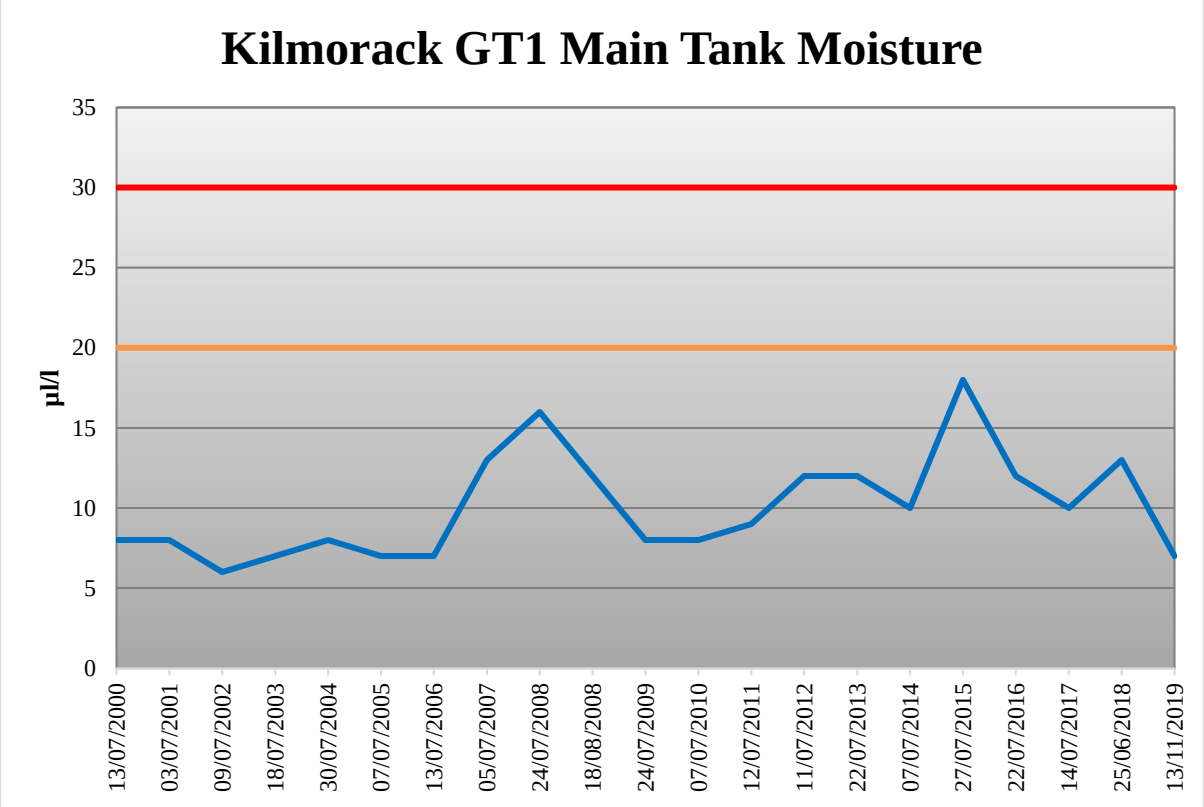


The historical acidity record contains 20 samples taken in the period of 2000 to 2018. The acidity levels are found to be exhibit an overall increasing trend which is indicative of oxidisation of the selector oil, which most likely is a result of main tank communication. Minor reductions observed are indicative of dilution by means of top ups or oil replacement during maintenance. Over the sample range all results are categorised as "Good" as defined by IEC 60422 for category B apparatus. The acidity is considered satisfactory.

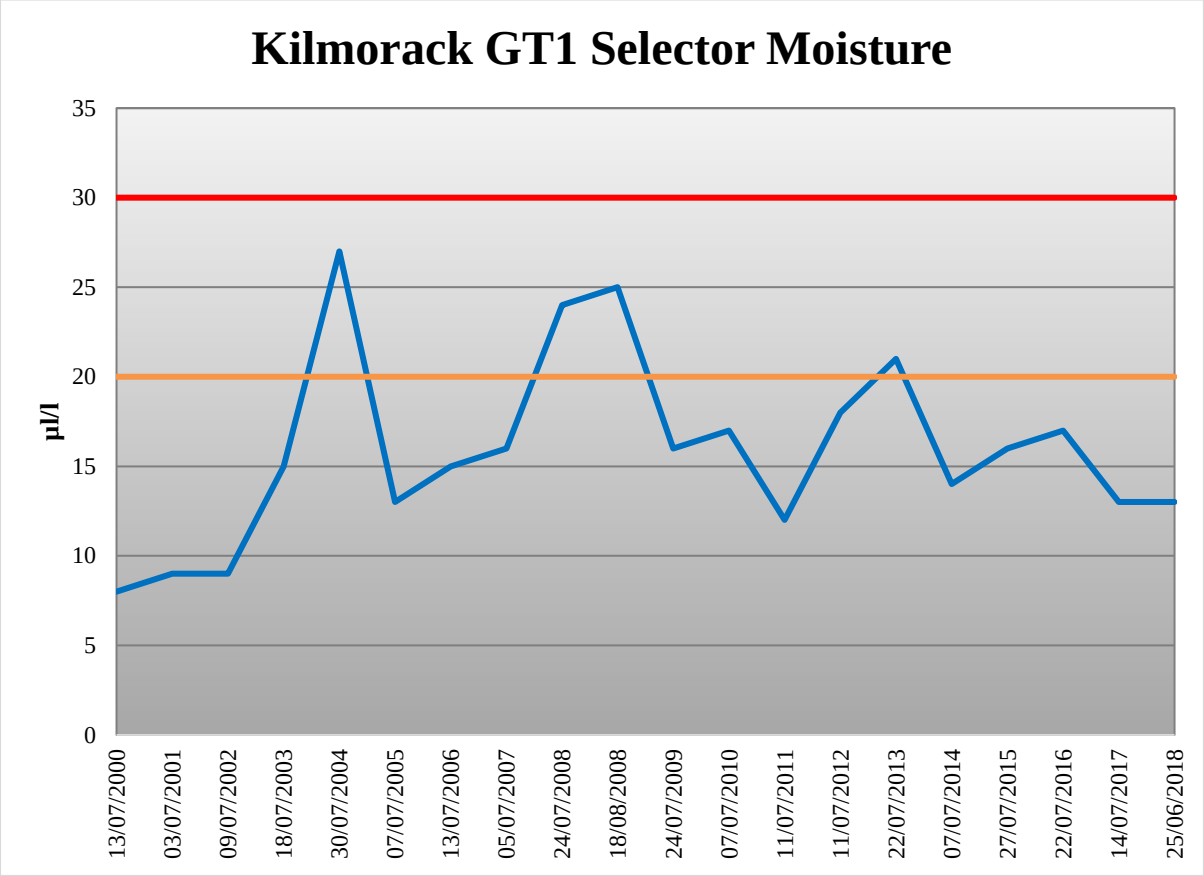
Moisture

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



The historical moisture data spans 21 samples taken in the period of 2000 to 2019. Over the operational life of the transformer the moisture levels have been dynamic yet have consistently been categorised as "Good", as detailed in IEC 60422. Moisture peaks at 18µl/l in July 2015. The most recent moisture result of 7µl/l is considered satisfactory and representative of recent historical results.

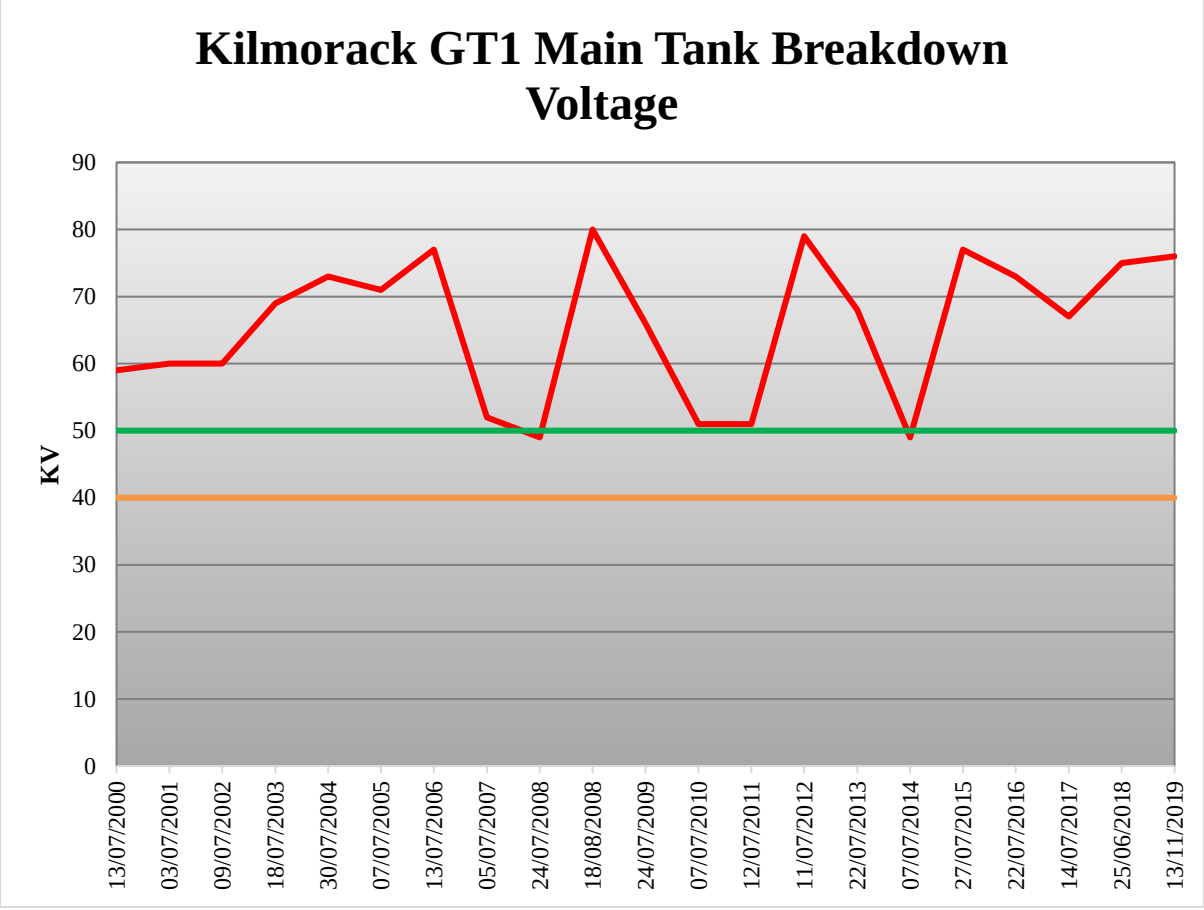


The historical moisture data spans 20 samples taken over the period of 2000 to 2018. Over the operational life of the transformer the moisture levels have been dynamic and have exhibited an increasing trend. Moisture results have predominantly been categorised as "Good", as detailed in IEC 60422 for category B apparatus yet have reached levels categorised as "Fair" on four separate occasions. A correlation in increased main tank moisture levels and peaks in selector moisture results is observed and suggests communication between the two. The peak value recorded in June 2004 was 27µl/l. The present moisture level is satisfactory and is fairly representative of the history.

Breakdown Voltage

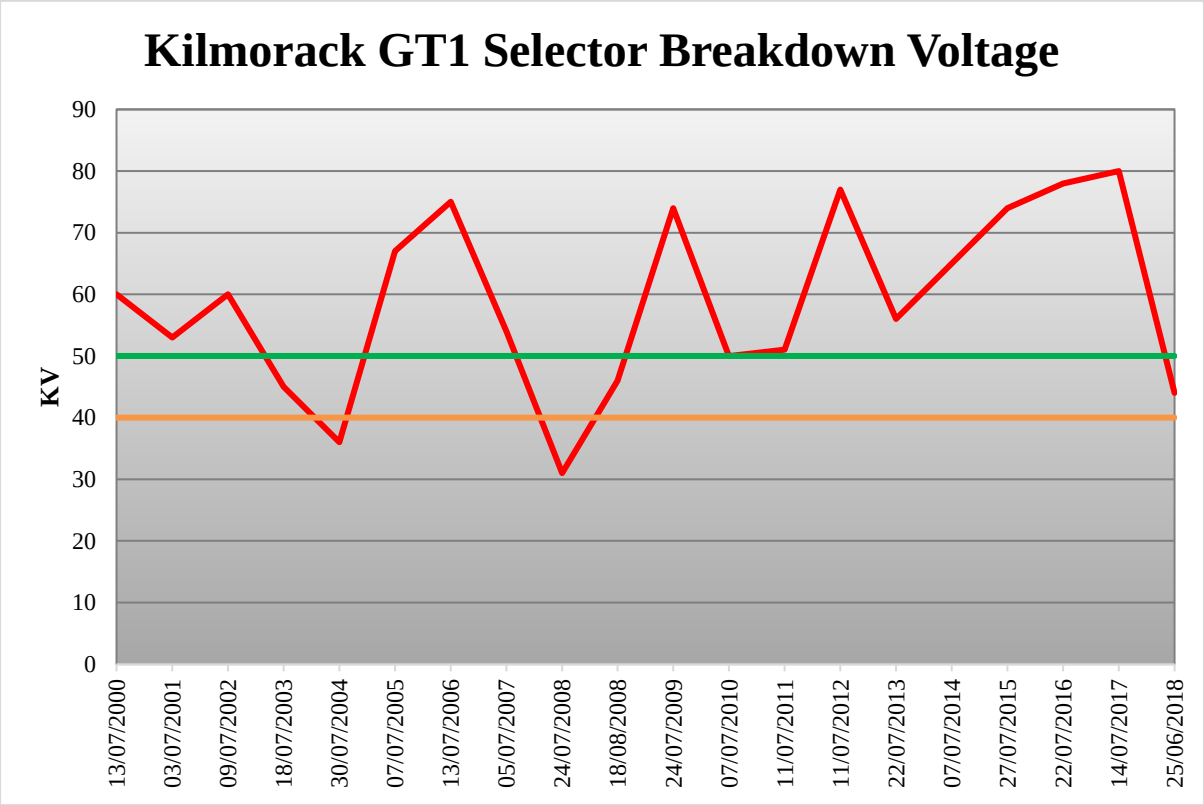
Breakdown voltage is a measure of the ability of the oil to withstand electric stress. Dry clean oil exhibits an inherently high breakdown voltage. Free water and other polar and non-polar contaminants reduce the breakdown voltage dramatically.

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. The breakdown voltage trend is observed to be dynamic over the sample range. Over the available history, the breakdown voltage is predominantly classed as "Good" as defined by IEC 60422. Although there are 2 samples within the "Fair" classification in July 2008 (49kV) & July 2014 (49kV). There is a correlation between increased main tank moisture levels and reduced breakdown voltage levels. The

most recent breakdown voltage is “Good” as defined by IEC 60422, and is considered representative of the breakdown voltage history.

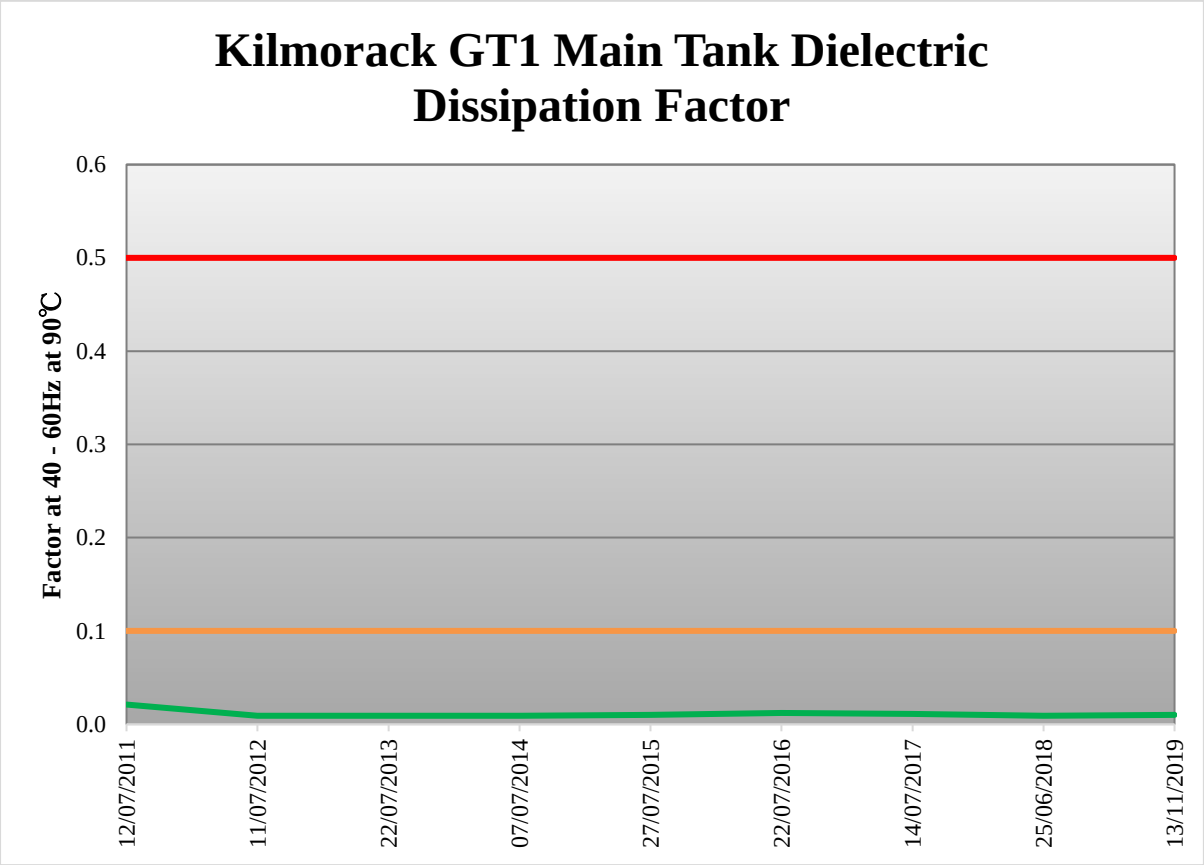


The historical breakdown voltage record spans from 2000 to the most recent sample in 2018. The breakdown voltage trend is observed to be very dynamic over the sample range. Over the available history, the breakdown voltage is predominantly classed as “Good” as defined by IEC 60422. Although there are 3 samples within the “Fair” classification in July 2003 (45kV), August 2008 (46kV) & July 2010 (50kV). Two samples also reach “Poor” categorisation in July 2004 (36kV) & July 2008 (31kV). There is a correlation between increased selector moisture levels and reduced breakdown voltage levels. The most recent breakdown voltage is “Fair” as defined by IEC 60422, and is considered to be fairly representative of the breakdown voltage history.

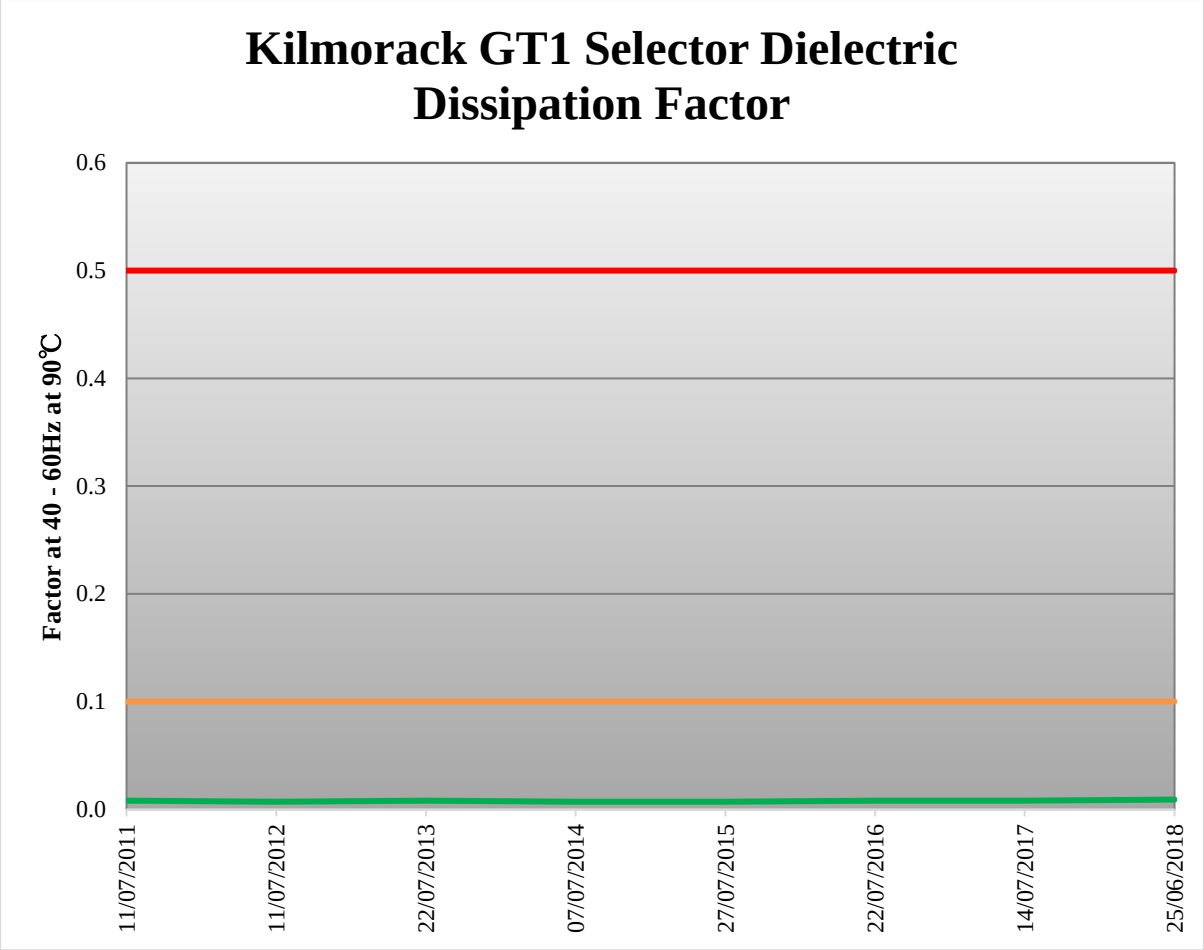
Dielectric Dissipation Factor

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**



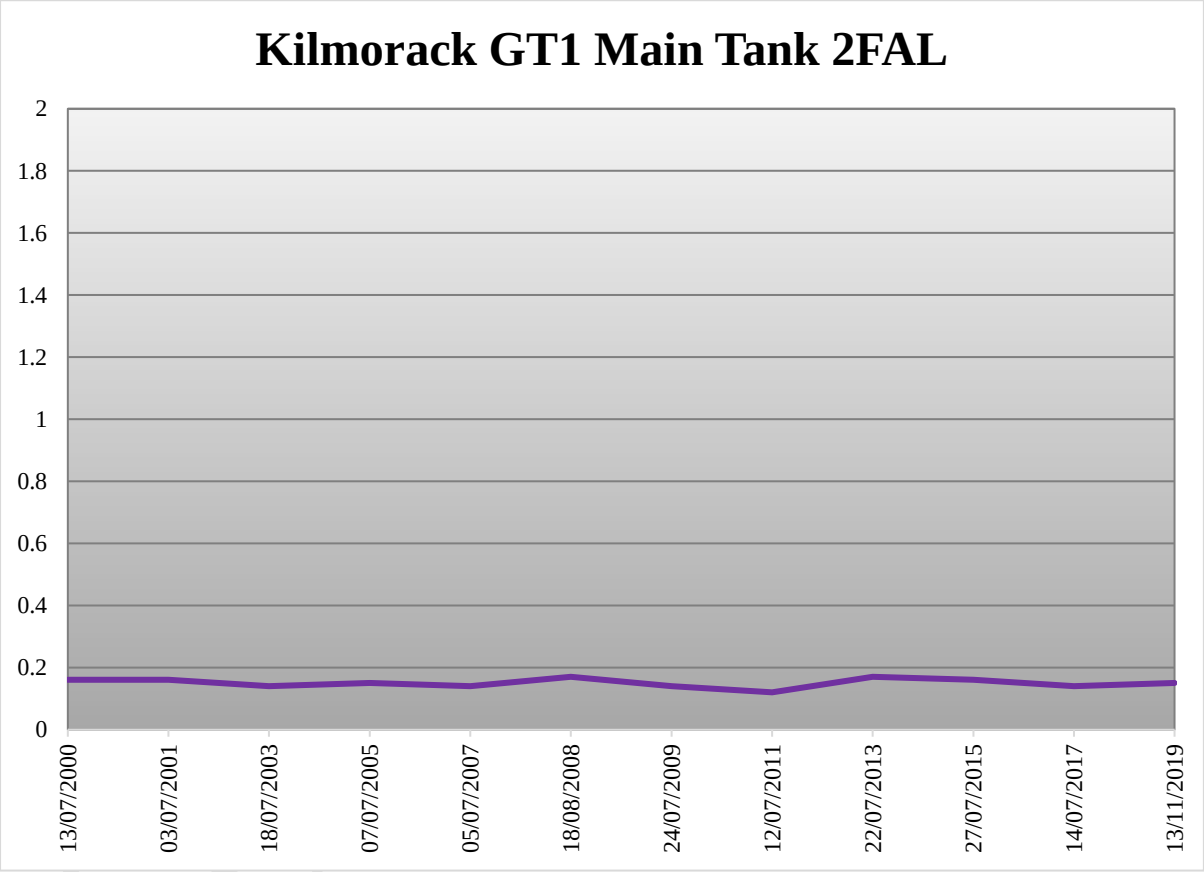
The dielectric dissipation factor trend is steady state and is constantly defined as "Good". This result is satisfactory.



The dielectric dissipation factor trend is steady state and is constantly defined as “Good”. This result is satisfactory.

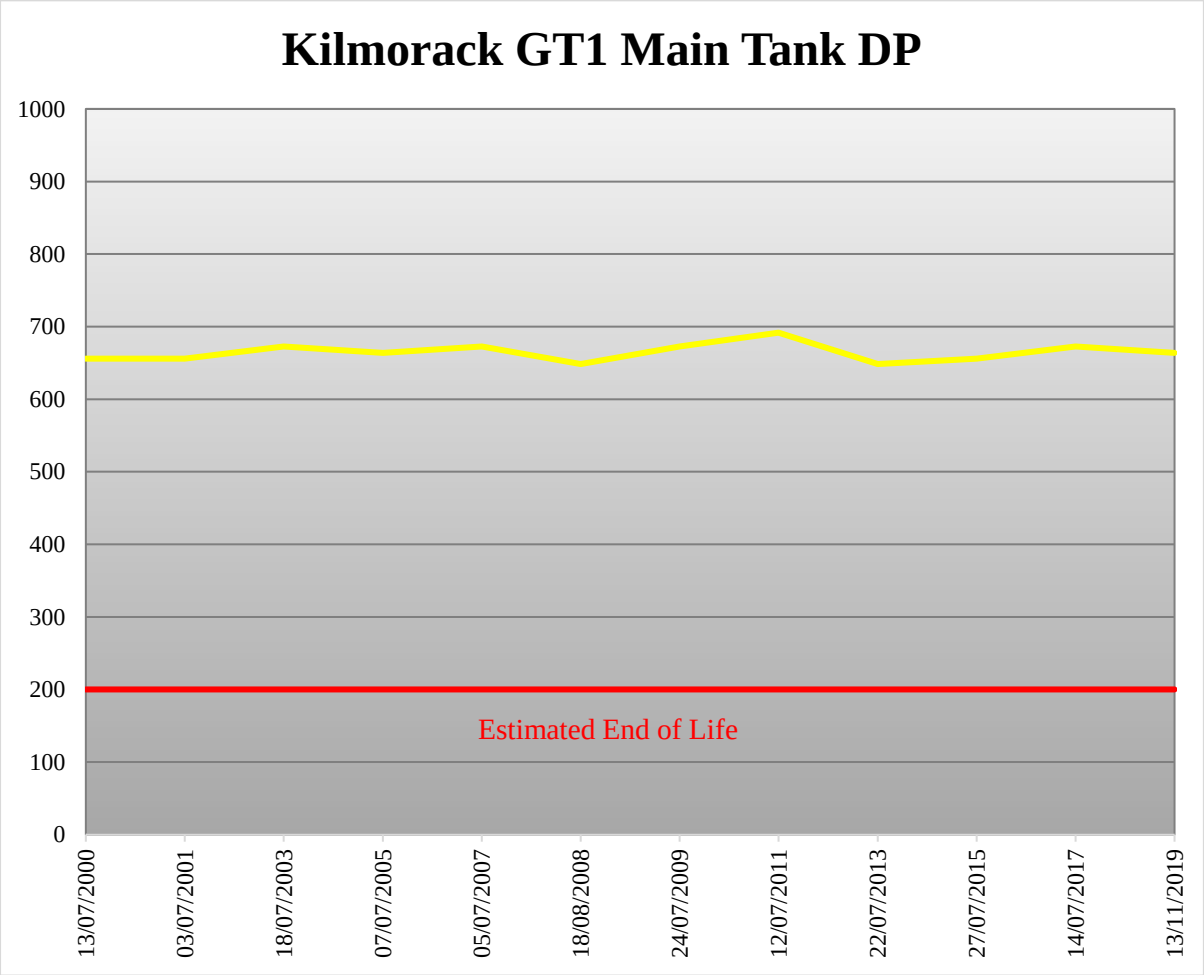
2FAL

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 November 2019. The 2FAL levels exhibits a relatively stable trend throughout the sample range. The final value recorded was 0.15 (Est DP 664), compared to the highest value recorded in the sampling period of 0.17 (Est DP 648). 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 August 2008). 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 56%

residual life remaining in the paper insulation. This suggests that the paper insulation is in a good condition given its age.



General

The following sections are made with reference to information contained within SSEN Report T2BP-ACR-0021 Revision 1.1 dated October 2019, henceforth referred to as document.

Previous Condition Assessments

Due to maintenance being carried out under contract by SSE Generation until 2017 it has not been possible to access maintenance records hence, no iSIM score can be affiliated with GT1 or any of its apparatus.

Security inspections have noted that the site does appears aged. Quarterly inspections noted access is no longer possible due to excessive pigeon droppings as well as an oil leak on the tap changer. Previous condition assessments, sourced from 2010, 2013 & 2015 have sourced which indicate birds and bats have been gaining access and leaving excessive droppings deeming GT1 inaccessible. Other comments worth of note are, leaking coolers, cable tray not earthed, oil absorbent material a fire hazard, tap changer heater exposed wiring. The leaking cooler bank has had containers placed below it to catch oil leaks which indicates the overall oil leaks of GT1. 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

A partial discharge survey was conducted in August 2016 by Elimpus (Report: ELI-KILM1-1601), with one source of partial discharge being detected. This partial discharge was associated with the yellow phase of connector 113 which was identified as the most likely source of partial discharge. This has been assessed by Elimpus to be related to the excessive bird droppings and it is suggested to clean all insulation surfaces prior to any future partial discharge survey. There is no evidence of partial discharge activity from transformer GT1 as evidenced by the absence of elevated levels of Hydrogen and Methane in the dissolved gas analysis.

Infra-Red Thermovision Survey

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

Impulse Protection

Unknown.

Load & Duty Cycle

No Load & duty cycle data was made available.

Historical Faults

No operational historical fault data was made available.

Maintenance

Until 2017, maintenance was carried out by SSE renewables. It has therefore not been possible to gain access to historic maintenance records.

Conclusion

Due to maintenance being carried out under contract by SSE Generation until 2017 it has not been possible to access maintenance records hence, no iSIM score can be affiliated with GT1 or any of its apparatus. However, security inspections have noted that the site does appear to be aged. Quarterly inspections noted access is no longer possible due to excessive pigeon droppings as well as an oil leak on the tap changer. Previous condition assessments, sourced from 2010, 2013 & 2015 have sourced which indicate birds and bats have been gaining access and leaving excessive droppings deeming GT1 inaccessible. Other comments worth of note are, leaking coolers, cable tray not earthed, oil absorbent material a fire hazard, tap changer heater exposed wiring. The leaking cooler bank has had containers placed below it to catch oil leaks which indicates the overall oil leaks of GT1 are deteriorating with time.

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.

The DGA does not presently exhibit any evidence of partial discharge, discharge, or thermal abnormality. There are two identifiable peaks in dissolved ethylene from the main tank 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 all categorised as "Good" as defined by IEC 60422:2013 indicating that the insulating oil has good dielectric properties.

The oil quality parameters for the tap changer selector comprising of moisture, acidity and DDF are all categorised as "Good" as defined by IEC 60422:2013. The breakdown voltage is categorised as "Fair" as defined by IEC 60422:2013.

In order to estimate the DP of the insulation system, the highest value of measured 2FAL shall be used (From August 2008) which was 0.17 (est DP 648). 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 56% residual life remaining in the paper insulation. This suggests that the paper insulation is in a good condition given its age.

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" 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 and presents a significant environmental hazard. 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.