Deanie
GT1
132/11kV
Transformer

Level 1 Condition Assessment Report
16th July 2020
Report: DEANGT1SHET200629 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 Deanie 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-0025 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 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.

There is an underlying thermal abnormality which is developing as evidenced by the presence of dissolved ethylene, in both the main tank and tap changer selector, which is increasing. To identify the source of the dissolved ethylene electrical testing would be required. Whilst these magnitudes of dissolved gases are still at relatively 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 long term 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. The DDF of the oil indicated the presence of a contaminant. The oil would require to be regenerated to restore the DDF levels to a quality defined as "Good" by IEC 60422, but this process would further dilute the concentrations of 2FAL and would render the estimated DP redundant as an ageing indicator. The elevated DDF will require to be investigated.

This transformer is internally in "reasonable condition" but has an underlying thermal abnormality and contamination of 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 DDF. This should be done every 3 months with additional oil analysis (over and above routine measurements) to include IFT, Sediment & Sludge and Particle Count.
- 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	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 Deanie 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 Y13868

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

Electrical Plant Details

Manufacturer:	Yorkshire Transformers
Serial Number:	Y13868
Year of Manufacture:	1962
ONAN Rating:	40 MVA
Ratio:	132/11 kV
Vector Group:	Unknown
Impedance:	Unknown
Tap Changer Manufacturer:	Fuller Electric
Tap changer Type:	HS315/33/300 DNDR1
Tap Changer Serial Number:	104460
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.

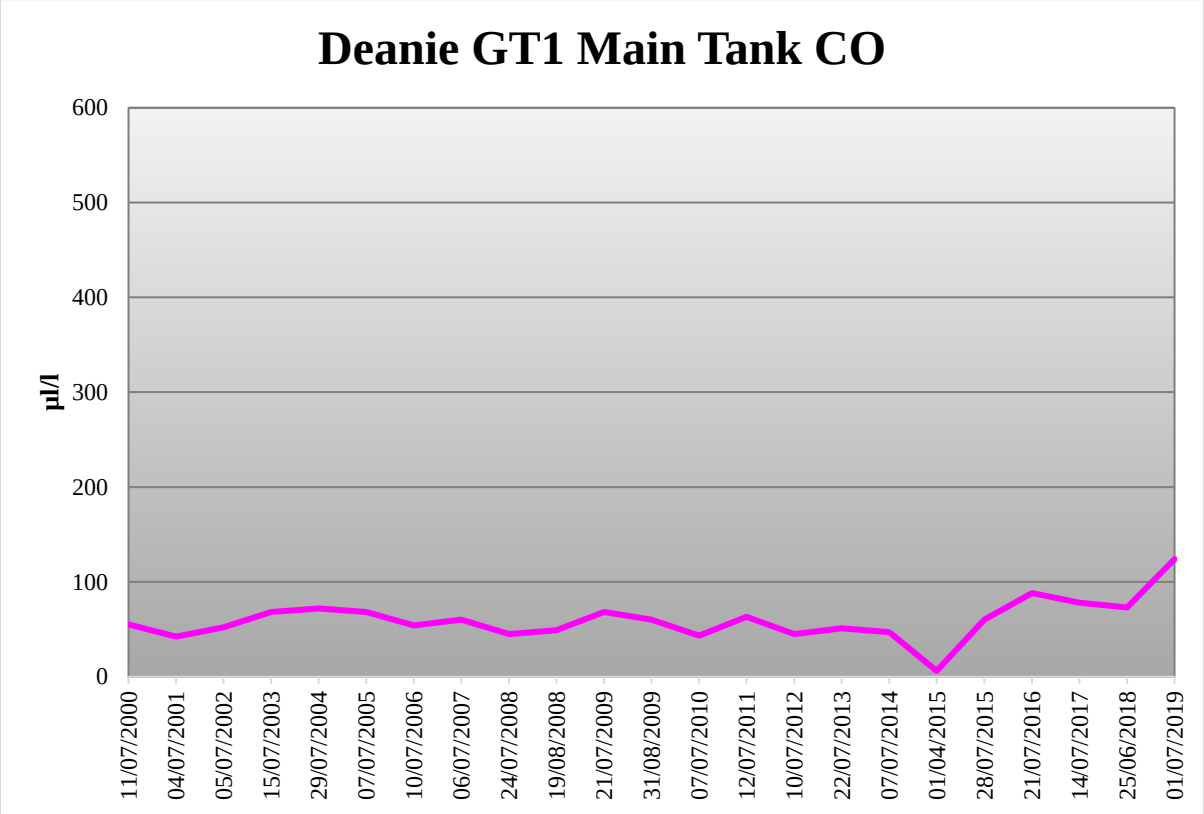
Main Tank Oil History

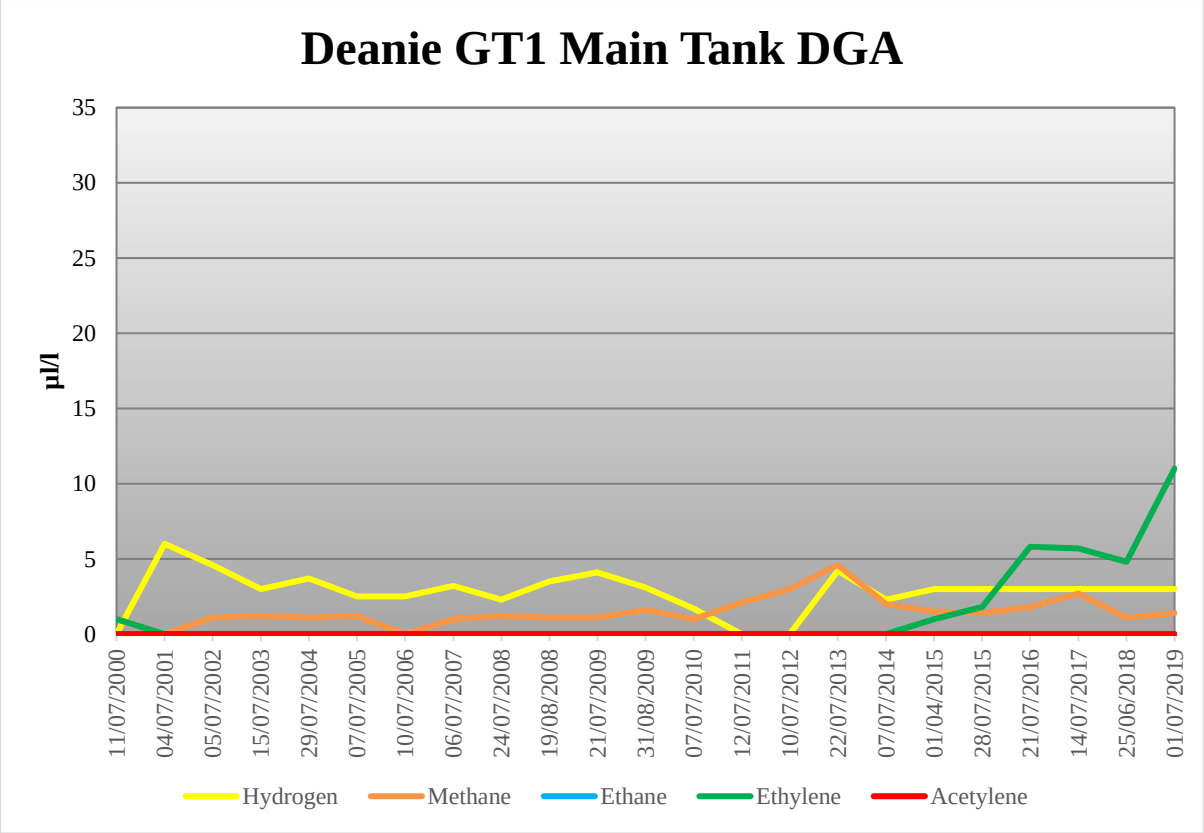
Dissolved Gas Analysis – Main Tank History

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 consistently remains below "typical values" specified in IEC 60599 over the sample period, peaking at 124µl/l in 2019. The paper insulation is likely in reasonable condition for its age.





Hydrogen and thermal gases methane & ethylene are present throughout the DGA history however, all remain at levels below "typical values" specified in IEC 60599. An increasing trend in Ethylene could merit increased sampling frequency due to the potential of an evolving thermal abnormality.

Application of the gas ratios, as defined in IEC 60599, [0, 0.33, unspecified] 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 "T3" condition, "Thermal faults, T > 700℃".

Analysis of the oil data shows no indication of partial discharge or discharge but there appears to be a developing thermal abnormality within the main tank.

Thermal Events:

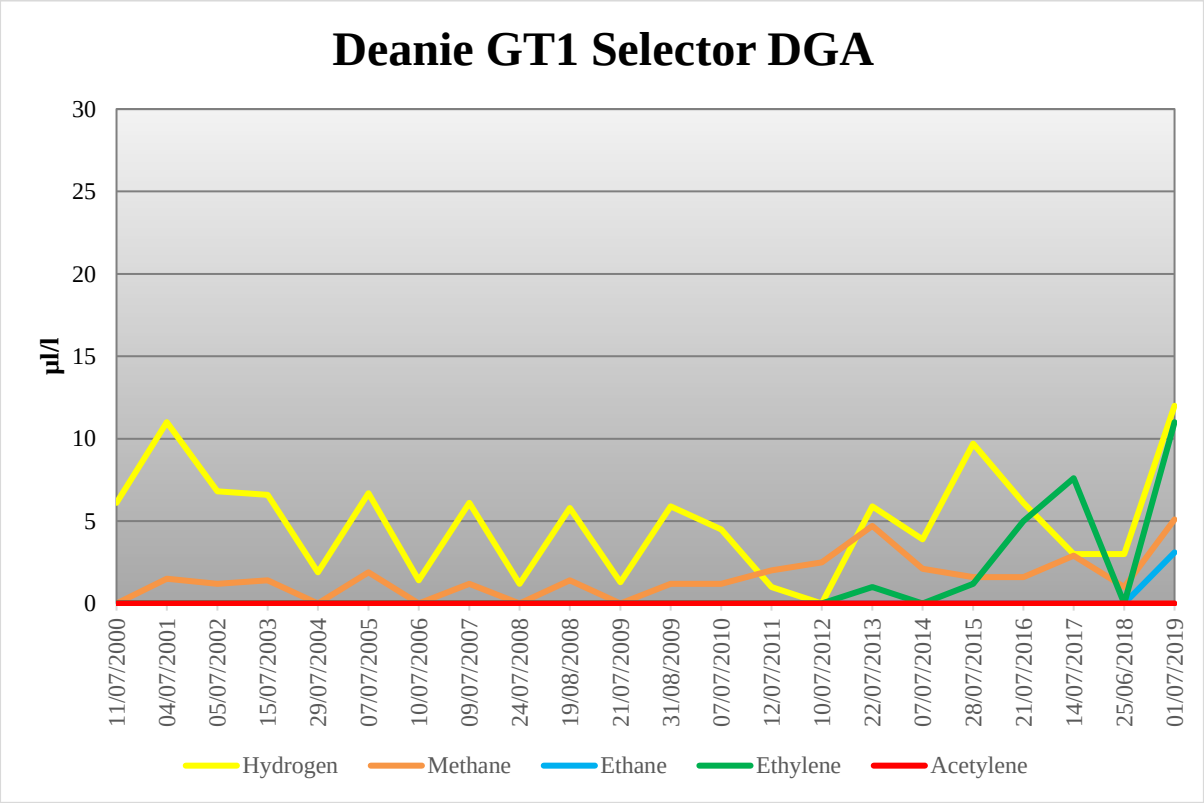
Since 2015 there has been a rising trend in the levels of dissolved ethylene within the main tank. This is coincident with a similar and mirroring trend in dissolved CO. This would suggest that there is a developing thermal fault that is causing insulation degradation. The dissolved ethylene within the main tank oil is, for practical purposes, in equilibrium with the selector tank.

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".



Hydrogen and thermal gases Methane, Ethane & Ethylene are present throughout the DGA history however, all remain at levels below "typical values" specified in IEC 60599. An increasing trend in Ethylene could merit increased sampling frequency due to the potential of an evolving thermal abnormality. In 2018 the diagnostic gas levels simultaneously decrease to very low levels suggesting that there has been an in intervention in the tap changer oil, most likely a maintenance or inspection.

Application of the gas ratios, as defined in IEC 60599, [0, 0.41,3.54] 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 "T3" condition, "Thermal faults, T > 700℃".

Analysis of the oil data shows no indication of partial discharge or discharge but there appears to be a developing thermal abnormality within the tap changer selector tank.

Thermal Events:

Since 2015 there has been a rising trend in the levels of dissolved ethylene within the tap changer selector. This is coincident with a similar and mirroring trend in dissolved main tank ethylene & CO. This would suggest that there is a developing thermal fault. The dissolved ethylene within the selector tank oil is, for practical purposes, in equilibrium with the main tank. There has been an intervention

(most likely a tap changer maintenance & inspection) in 2018, as characterised by the simultaneous reduction in all dissolved gas levels to very low levels.

Discharge Events:

None

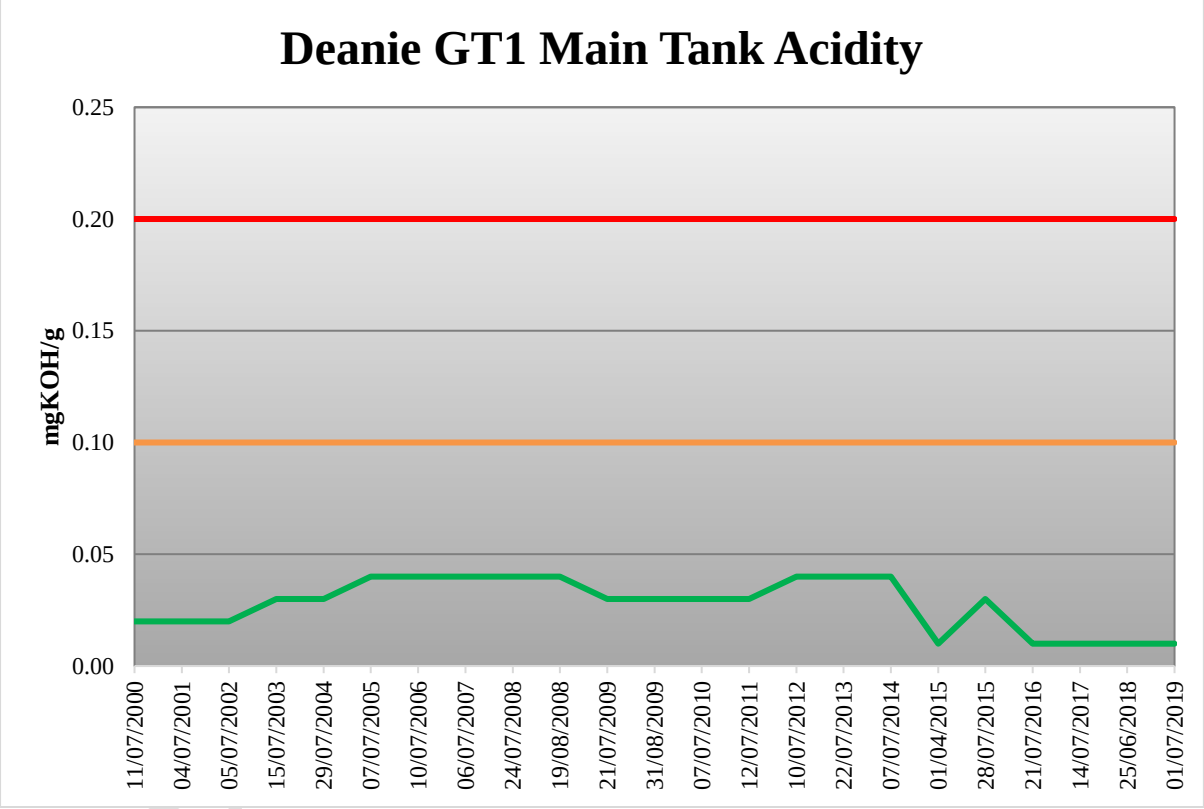
Main Tank Oil Quality Analysis

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.

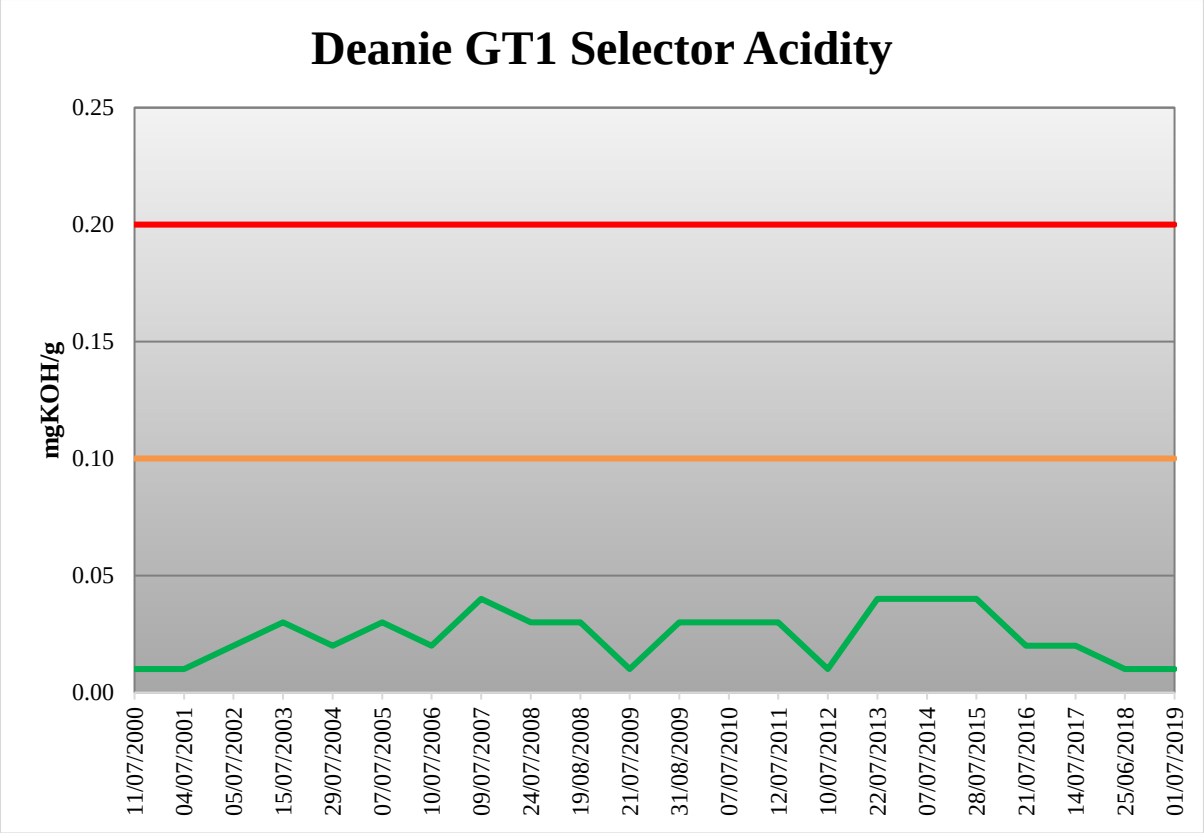
Acidity

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 23 samples taken between 2000 and 2019. The acidity levels are found to exhibit an overall decreasing trend particularly around 2014 & 2015 suggesting that the main tank oil has been diluted or been subjected to an intervention. Across the sample range the acidity levels are consistently classified as "Good" by definition in IEC 60422, for category B apparatus. The most recent acidity measurement was found to be 0.01mgKOH/g is categorised as "Good" and is representative of recent acidity historical results.

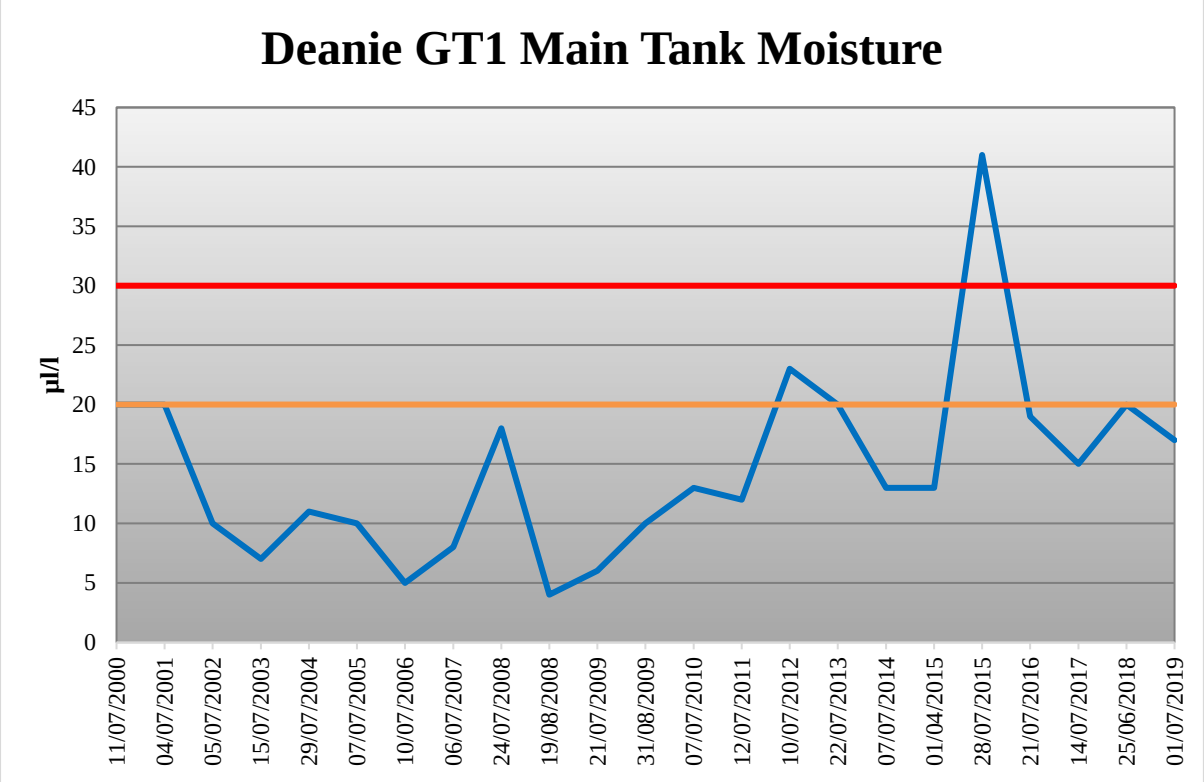


The historical acidity record contains 22 samples taken in the period of 2000 to 2019. The acidity levels are found to be relatively stable over the sample period and are categorised as “Good” as defined by IEC 60422 for category B apparatus. The most recent acidity measurement was found to be 0.01mgKOH/g is categorised as “Good” and is representative of recent acidity historical results.

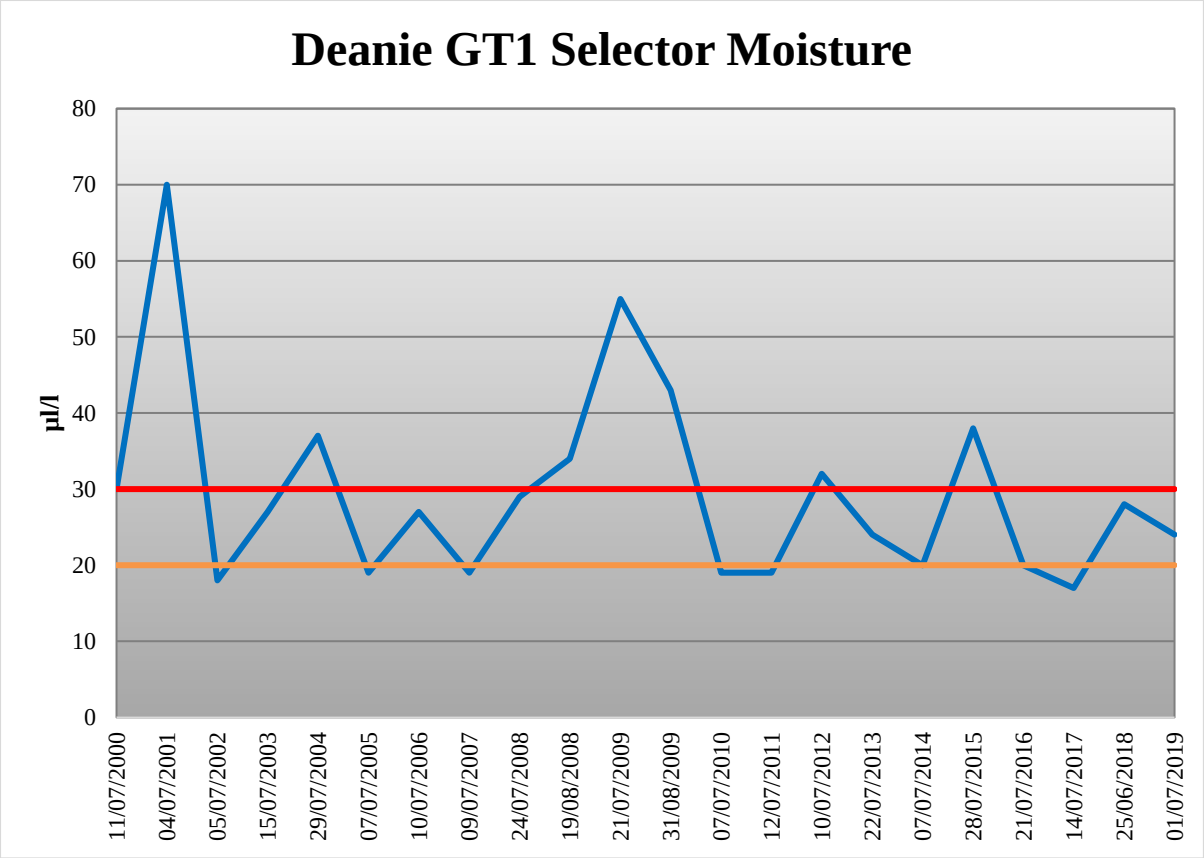
Moisture

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 23 samples overt the period of 2000 to 2019. Over the operational life of the transformer the moisture levels have been dynamic and clearly display an increasing trend. Most historical moisture results are categorised as "Good", as detailed in IEC 60422 however, on four occasions moisture increases to reach "Fair" moisture content limits as well as exceeding 30µl/l once to be categorised as "Poor", a peak moisture content level of 41µl/l in July 2015. It is not known if this was due to a contaminated sample or if there was any intervention carried out on the moisture management system. The most recent moisture measurement of 17µl/l is considered to be representative of the history and is satisfactory.

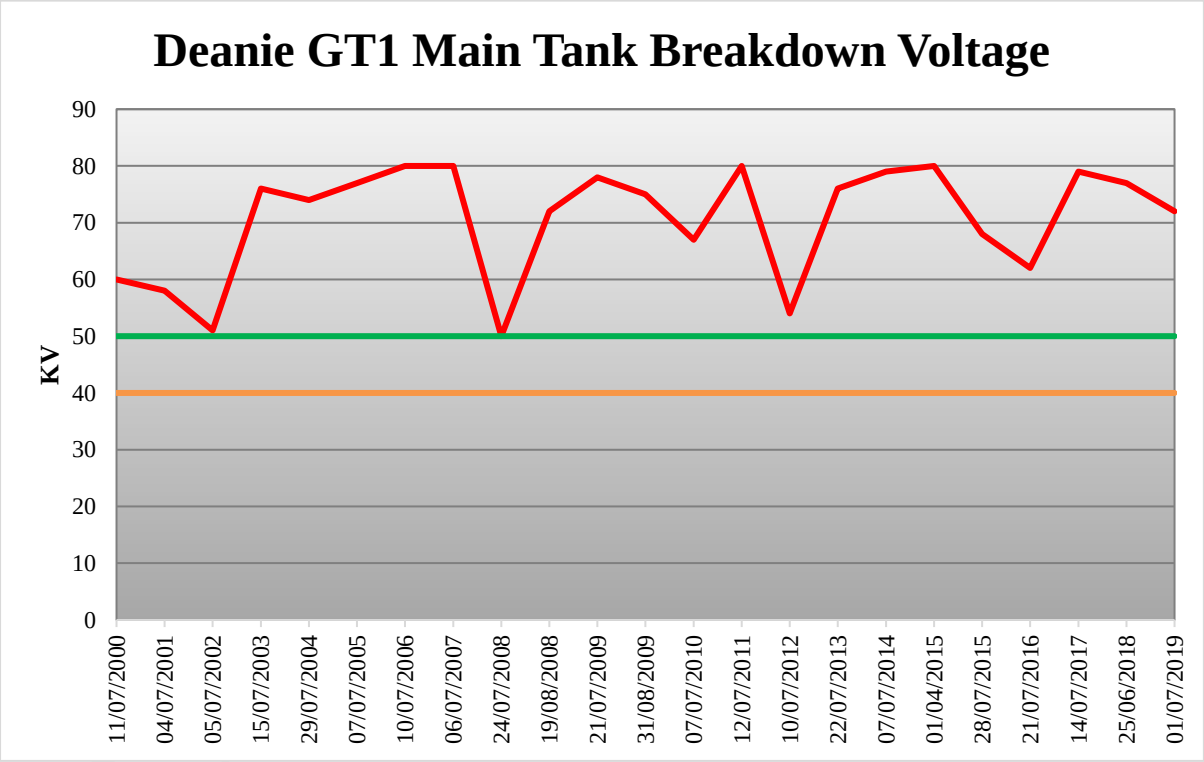


The historical moisture data spans 22 samples overt the period of 2000 to 2019. Over the operational life of the transformer the moisture levels have been dynamic and display an overall increasing trend. Historical moisture results fluctuate between all are categorisations of "Good", "Fair" & "Poor" as detailed in IEC 60422 for category B apparatus. Peak moisture content of 70µl/l is observed in July 2001. The most recent result of 24 µl/l, categorised as "Fair", is acceptable but not considered representative of recent historical results. The status and operational capability of the tap changer moisture management system should be checked.

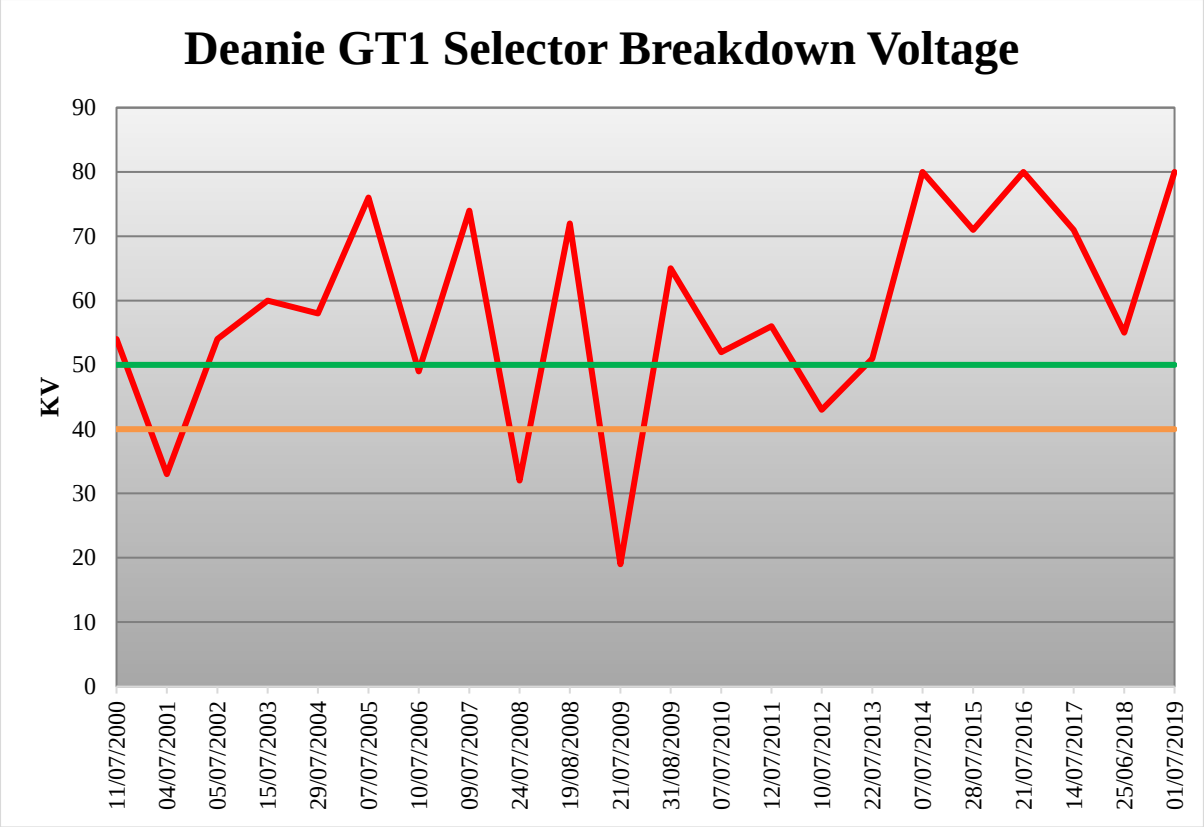
Breakdown Voltage

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 23 samples. With the exception of the sample from July 2008, which is categorised as "Fair", all samples are categorised as "Good" as detailed in IEC 60422 for category B apparatus. The overall trend exhibited is dynamic. There is an observable correlation between increased moisture content within the main tank and a reduction in breakdown voltage level. Overall, the breakdown voltage level is satisfactory.

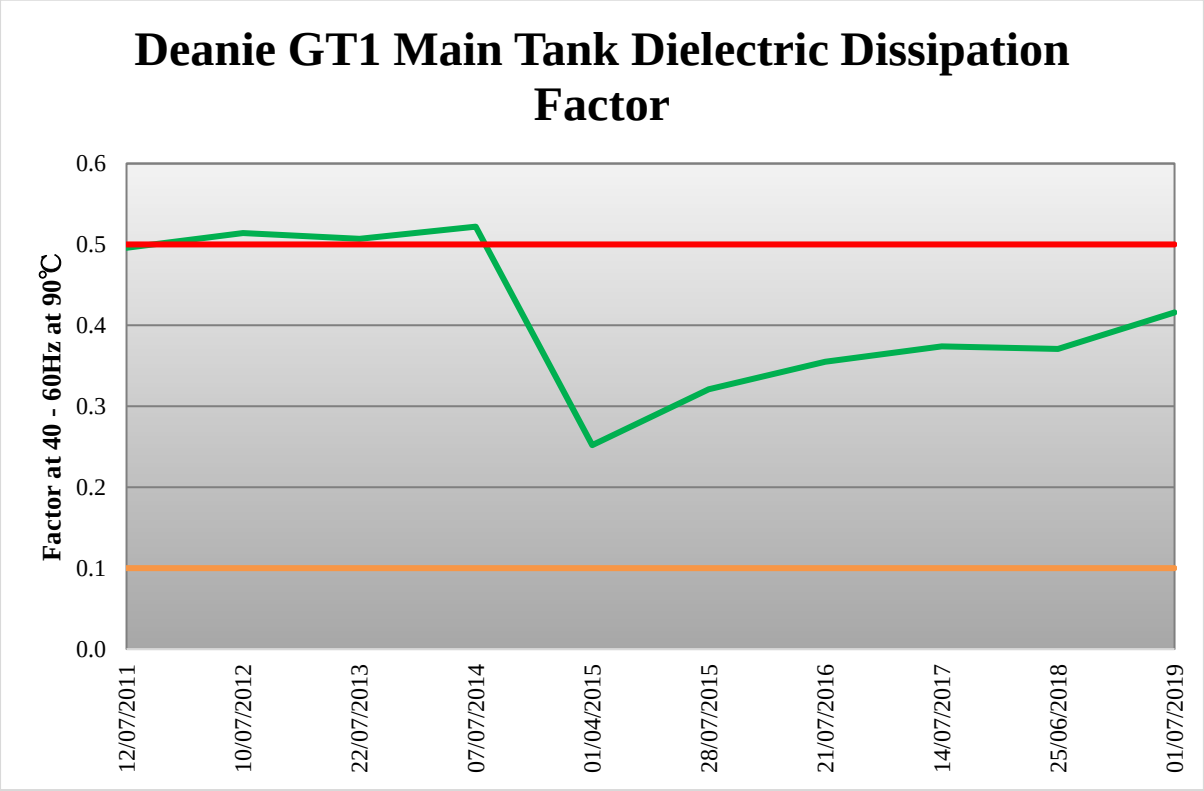


The historical breakdown voltage record spans the period of 2000 to 2019 and is inclusive of 22 samples. The dynamic trend displayed has resulted in categorisation of "Good", "Fair" & "Poor" as detailed in IEC 60422, over the historical sample range. There is an observable correlation between increased moisture content within the main tank and a reduction in breakdown voltage level. Overall, the breakdown voltage level is not satisfactory. The status and operational capability of the tap changer moisture management system should be checked.

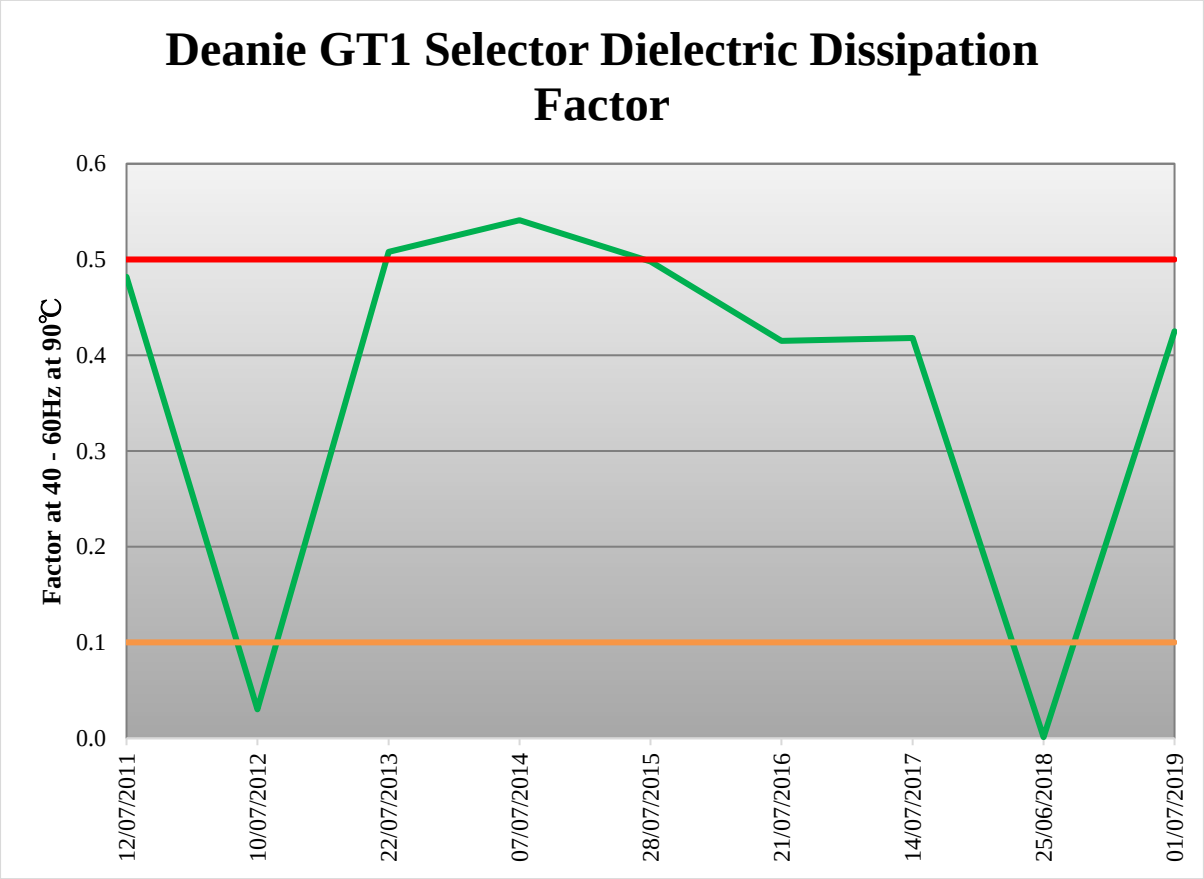
Dielectric Dissipation Factor

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**



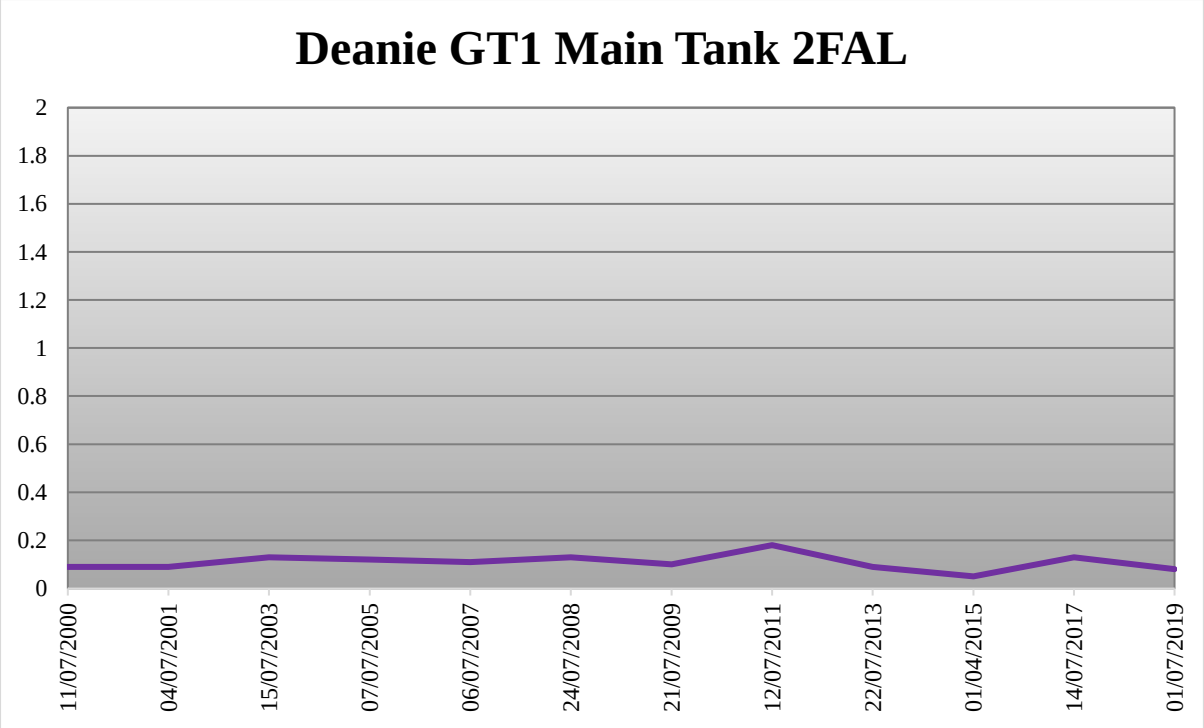
The dielectric dissipation factor historical sample range spans the period of 2011 to 2019 and is inclusive of 10 samples. There is step change improvement in DDF between July 2014 & 2015 most likely due to dilution of the main tank oil or possibly due to reconditioning of the oil. Following this, there is a gradual increasing trend in DDF. This would suggest that there is a source of contamination within the oil system. The most recent result is categorised as "Fair" and is considered representative of the recent historical sample range.



The dielectric dissipation factor historical sample range spans the period of 2011 to 2019 and is inclusive of 9 samples. The overall trend is extremely dynamic as categorisations of "Good", "Fair" & "Poor" are relevant over the limited sample range. The two significant dips in DDF in 2012 and 2018, where the DDF is considered "Good" is most likely consistent with a selector maintenance and the oil would be replaced with new or reclaimed oil. Following 2012, the DDF returns to a "Poor" condition with a value of 0.54 which would suggest that the contaminant has migrated from the main tank and affected the DDF of the selector oil. The improvement in DDF from 2014 to 2016 is most likely due to a dilution of the main tank oil which has migrated into the selector. The most recent result is categorised as "Fair" and is considered representative of the recent historical sample range.

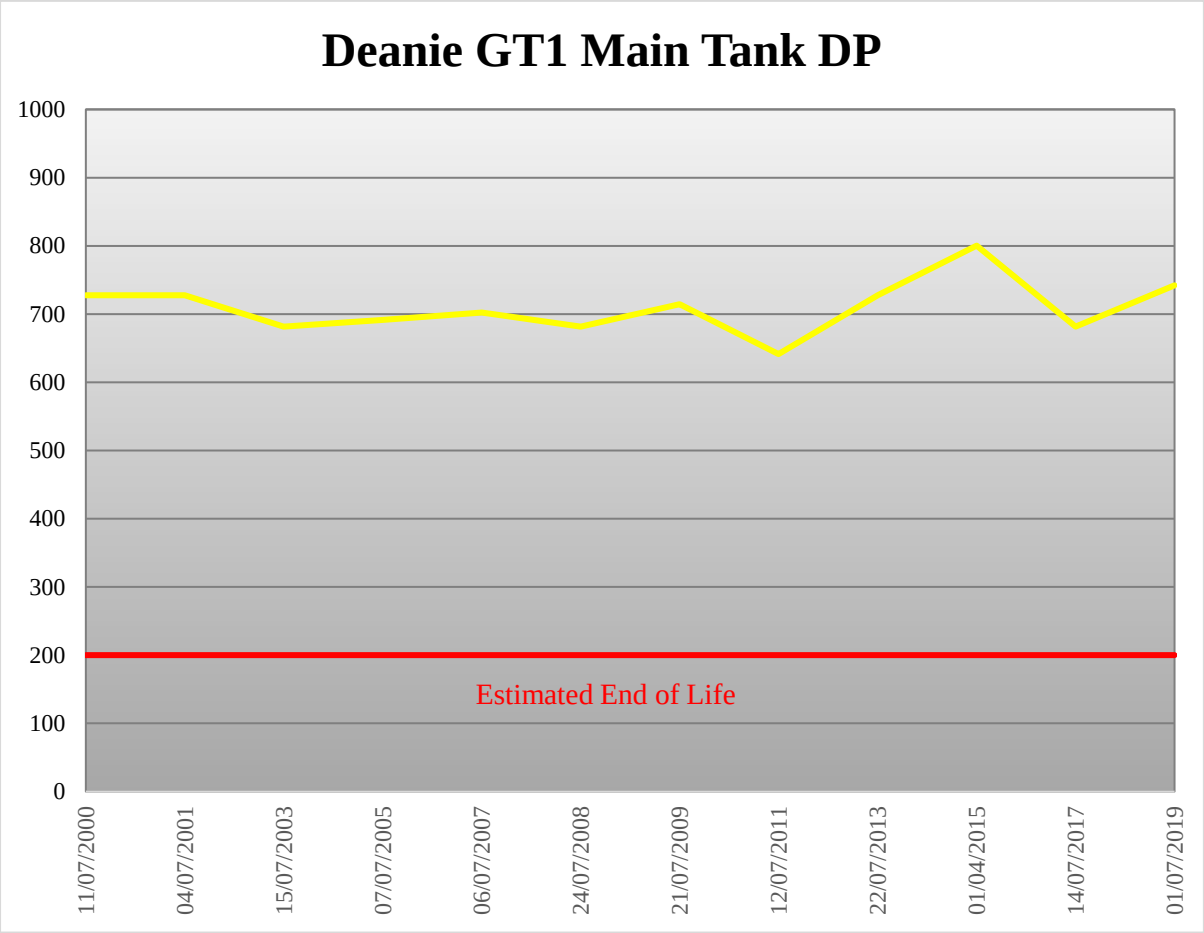
2FAL

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 2019. The 2FAL levels show a relatively stable trend over the sample range however, evidence of dilution by the addition of new or reclaimed oil into the main tank is evidenced by decreasing 2FAL. The final value recorded was 0.08 (Est DP 742), compared to the highest value recorded in the sampling period of 0.18 (Est DP 641). 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 2007). 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 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 SSEN Report T2BP-ACR-0025 Revision 1.1 dated October 2019, henceforth referred to as document.

Previous Condition Assessments

The iSIM inspection data for GT1 is categorised as level 4 (Serious deterioration or damage that requires specific action in the short term). This highlights that immediate action is required to improve GT1 overall condition. This is substantiated with the photographic evidence contained within the document with corrosion of the main tank and oil leaks from HV bushing turrets recorded. Comment is also made on the deterioration of the concrete bases and foundations of GT1.

The tap changer is recoded as category 2 (Apparent normal wear, intervention to be done in the next refurbishment). Although in a better condition than the main tank, remedial action is required.

Partial Discharge Survey

A partial discharge survey was conducted in January 2017 by Elimpus (Report: Barry Cairns "DEANIE 132kV AIS PD SURVEY,2017), with no indication of partial discharge being found. 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 2015 with no abnormalities found.

Impulse Protection

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

Load & Duty Cycle

No load & duty cycle data was provided for GT1.

Historical Faults

08-11-2017 - Breather requires recharge

17-10-2018 - Approved breather junction box has water ingress and corrosion, although still has supply. Believe the breather to be faulty.

23-01-2019 - Silica needs changing.

06-04-2018 - Breather needing recharged.

No operational historical fault data was made available.

Maintenance

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 - 27/09/2002

GT1TAP - MW 132kV Grid Transformer Tap changer maintenance - 27/09/2002

GT1TAP - MW 132kV Grid Transformer Tap changer maintenance - 24/09/2004

GT1 - MW 132kV Grid Transformer Maintenance - 11/08/2006

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

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

GT1TAP - MW 132kV Grid Transformer Tap changer maintenance - 30/08/2010

GT1 - MW 132kV Grid Transformer Maintenance - 08/09/2017

GT1TAP - MW 132kV Grid Transformer Tap changer maintenance - 08/09/2017

Conclusion

The iSIM inspection data for GT1 is categorised as level 4 (Serious deterioration or damage that requires specific action in the short term). This highlights that immediate action is required to improve GT1 overall condition. This is substantiated with the photographic evidence contained within the document with corrosion of the main tank and oil leaks from HV bushing turrets recorded. Comment is also made on the deterioration of the concrete bases and foundations of GT1.

The tap changer is recoded as category 2 (Apparent normal wear, intervention to be done in the next refurbishment). Although in a better condition than the main tank, remedial action is required.

The DGA does not exhibit any evidence of partial discharge or discharge but there appears to be a developing thermal abnormality within the main tank. Since 2015 there has been a rising trend in the levels of dissolved ethylene within the main tank. This is coincident with a similar and mirroring trend in dissolved CO. This would suggest that there is a developing thermal fault that is causing insulation degradation. The dissolved ethylene within the main tank oil is, for practical purposes, in equilibrium with the selector tank as the tap changer is communicating. 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 are all categorised as "Good" as defined by IEC 60422:2013 indicating that the insulating oil has good dielectric properties. The DDF is categorised as "Fair" as defined by IEC 60422:2013 but has a dynamic history and has been measured as "Poor". DDF is sensitive to the presence of soluble polar contaminants or ageing products, which are thought to originate from the main tank. This should be kept under surveillance and may require intervention.

Acidity is the only oil quality parameter for the tap changer selector that is categorised as "Good" as defined by IEC 60422:2013. Moisture and DDF are categorised as "Fair" as defined by IEC 60422:2013. The breakdown voltage is categorised as "Poor". The dielectric properties of the selector oil have been compromised by the contamination from the migration of oil from the main tank as evidenced by the elevated DDF and moisture ingress from atmosphere, most likely from a breather that requires maintenance or a compromised moisture management system. This should be kept under surveillance and may require intervention.

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 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” but has an underlying thermal abnormality and contamination of 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 DDF. This should be done every 3 months with additional oil analysis (over and above routine measurements) to include IFT, Sediment & Sludge and Particle Count.
- 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.