St Fillans GT1 132/11kV Transformer

Level 1 Condition Assessment Report 15th July 2020 Report: SFILGT1SHET200629 FINAL

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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 St Fillans 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 T2-EJP-0041 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 deteriorate by ageing during the RIIO T2 period. There is an increased risk of failure due to an underlying thermal abnormality which will require monitoring in the form of increased DGA surveillance and may require enhanced maintenance within this period.

There is evidence that the transformer has external ageing which requires further inspection and evaluation. Given that the transformer is located in close proximity to a water course, the transformer should be considered as an environmental hazard until such times as the oil leaks have been assessed. There is a reported issue with "availability of spares" which needs to be investigated.

There is an underlying thermal abnormality as evidenced by the presence of dissolved ethylene levels in the main tank. 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 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 40% life remaining is considered optimistic. The oil is oxidised which would require to be regenerated to restore the oxidation levels to a quality defined as "Good" by IEC 60422, but this process would further dilute the concentrations of 2FAL. This would render the estimated DP redundant as an ageing indicator.

The conclusion of the proposed detailed evaluation, taking into account all risk factors associated with GT1, should indicate if the transformer is to be recommended for replacement or subjected to a programme of refurbishment.

In order to further assess and manage the condition of this transformer, the following recommendations are made:

- Investigation into a lack of available spare parts. This should be thoroughly risk assessed with particular reference to the longevity of the transformer.
- Detailed inspection of the asset – outage required.
- 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.

- Inspection and assessment of the moisture management system.
- Following detailed inspection continue with routine inspection.
- Increase the oil sampling frequency to 6 months to keep the dissolved ethylene under surveillance.
- 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
15th July 2020	FINAL	IBB Hunter	Editorial & 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 St Fillans 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 35228

This transformer was manufactured in 1958, and was installed and commissioned at St Fillans 132kV substation.

Electrical Plant Details

Manufacturer:	Bruce Peebles
Serial Number:	35228
Year of Manufacture:	1958
ONAN Rating:	25 MVA
Ratio:	132/11 kV
Vector Group:	Unknown
Impedance:	Unknown
Tap Changer Manufacturer:	N/A
Tap changer Type:	N/A
Tap Changer Serial Number:	N/A
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.

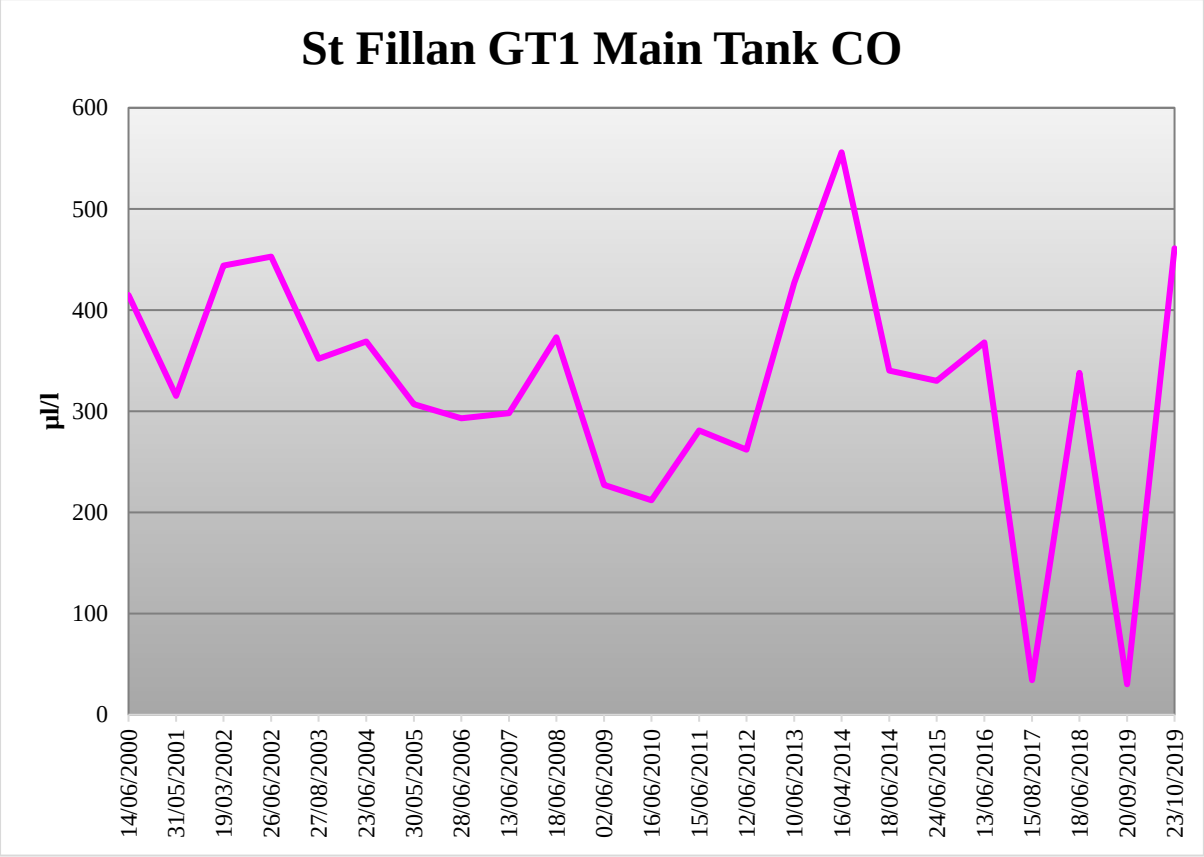
Main Tank Oil History

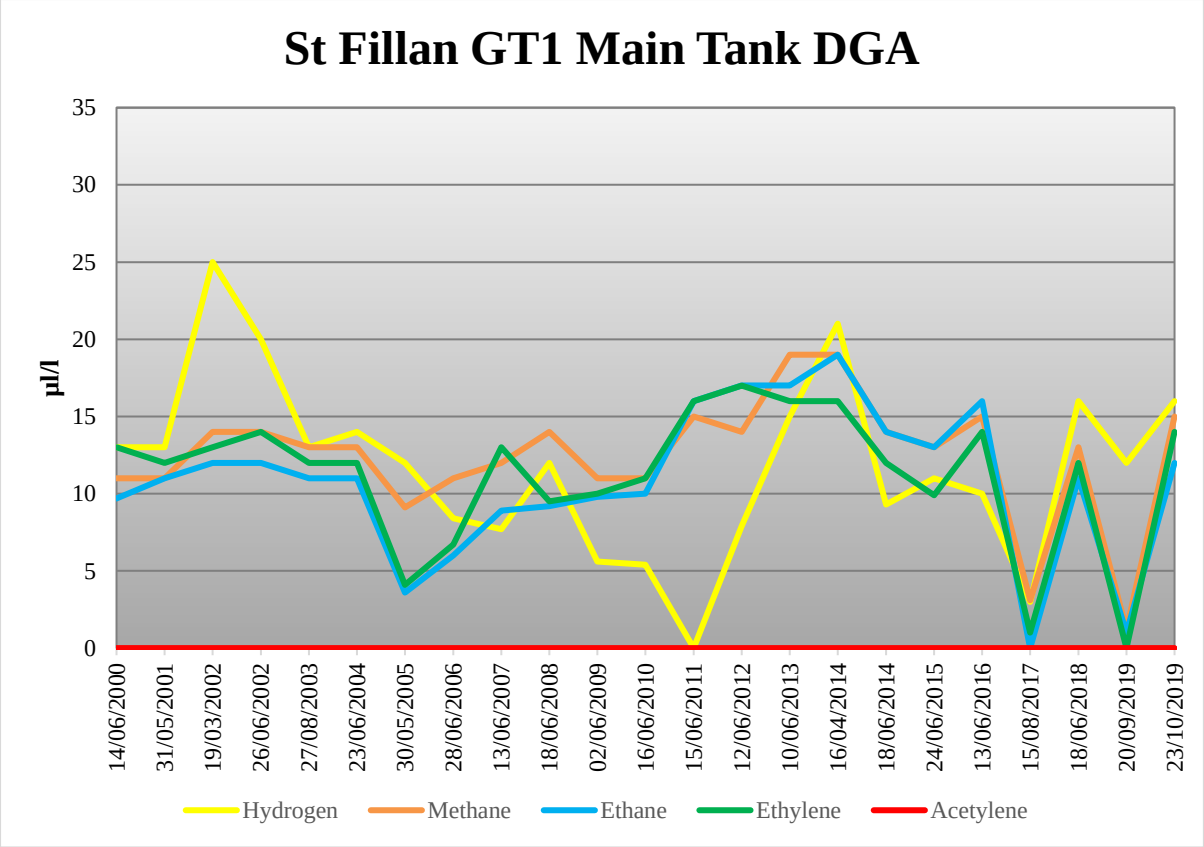
Dissolved Gas Analysis – Main Tank History

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 dynamic but remains within "typical values" specified in IEC 60599 over the sample period, peaking at 556µl/l in 2014. Concentrations of CO at this magnitude is indicative of cellulose degradation. The paper insulation is likely in an aged condition.





Hydrogen and thermal gases methane, ethane & ethylene are present throughout the DGA history however, all remain at levels well below "typical values" specified in IEC 60599. A dynamic trend in dissolved ethylene could merit increased sampling frequency due to the presence of an underlying thermal abnormality.

There is a correlation between dissolved CO, methane, ethane & ethylene trends which suggests that the thermal abnormality is causing ageing of the paper insulation. It is considered that the dissolved methane is a residual effect of the dissolved ethylene, but there could be a contribution to this by a low level partial discharge, normally characterised by the presence of hydrogen and methane. If this partial discharge was to exist it would most likely be undetectable by other means due to the low level of activity.

Application of the gas ratios, as defined in IEC 60599, [0,0.93,1.16] 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.

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

Thermal Events:

Thermal abnormality present over entire sample range. Dissolved ethylene should be kept under surveillance.

Discharge Events:

Possible partial discharge but though to be of such a low level as to be negligible for practical purposes.

Dissolved Gas Analysis-Tap Changer

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”.

Transformer GT1 is not furnished with a tap changer.

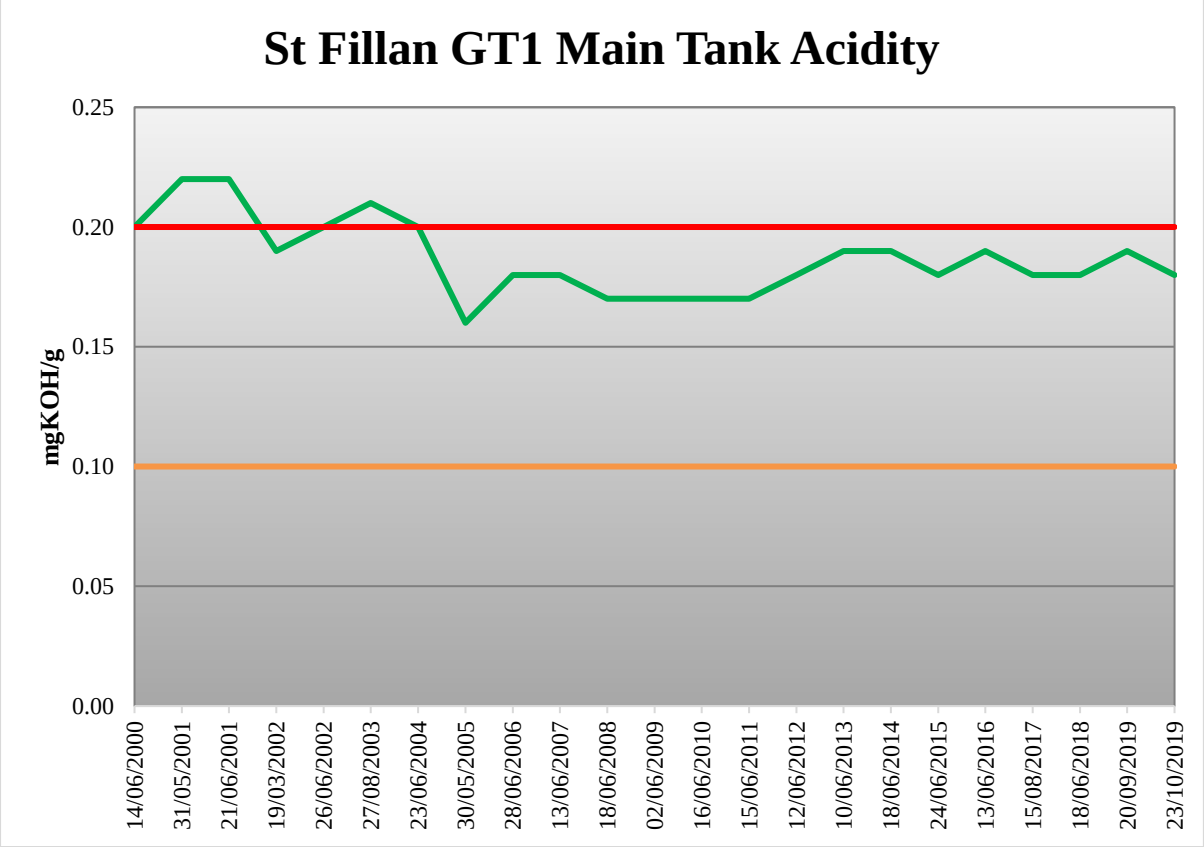
Main Tank Oil Quality Analysis

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**



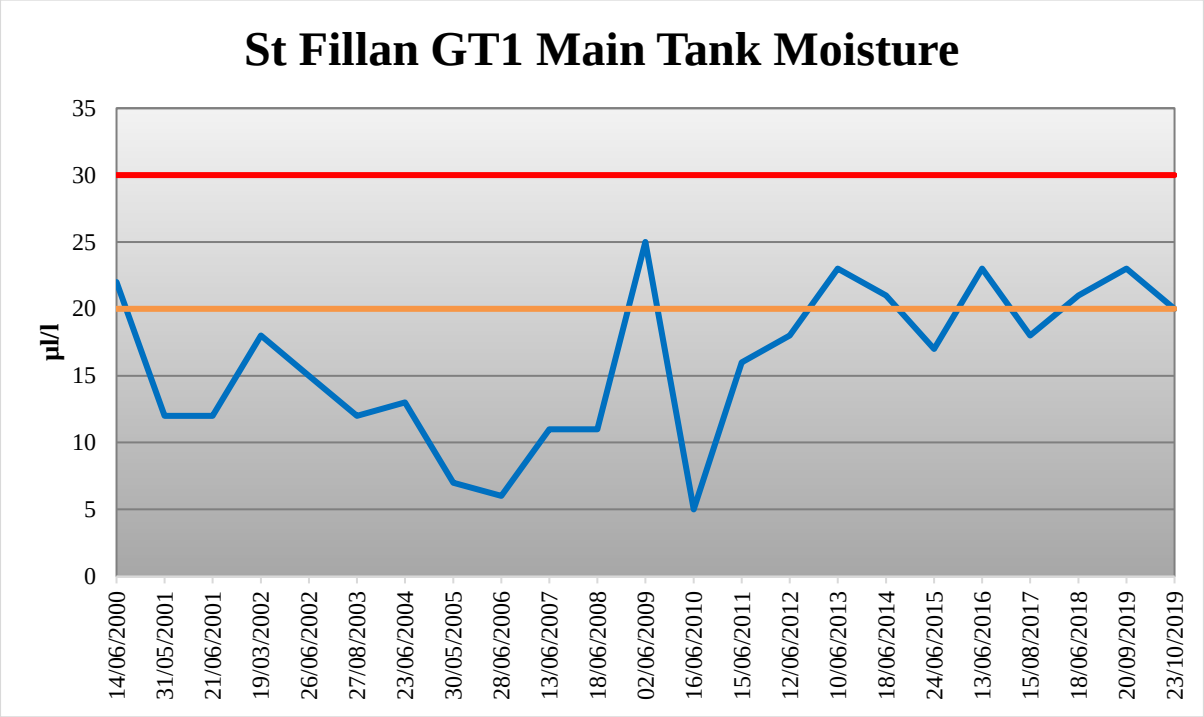
The historical acidity record contains 23 samples taken in the period of 2000 to 2019. The acidity levels are found to exhibit a minor decreasing trend over the sample range indicative of a dilution effect caused by top ups of new or reclaimed oil. The oil is oxidised but exhibits a stable level of acidity. Over the sample range acidity levels have reached levels categorised as "Poor" on six occasions. All remaining samples are categorised as "Fair "as defined by IEC 60422 for category B apparatus. Overall, the

acidity is considered unsatisfactory and would require to be regenerated to restore the acidity level to "Good" as defined by IEC 60422.

Moisture

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

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

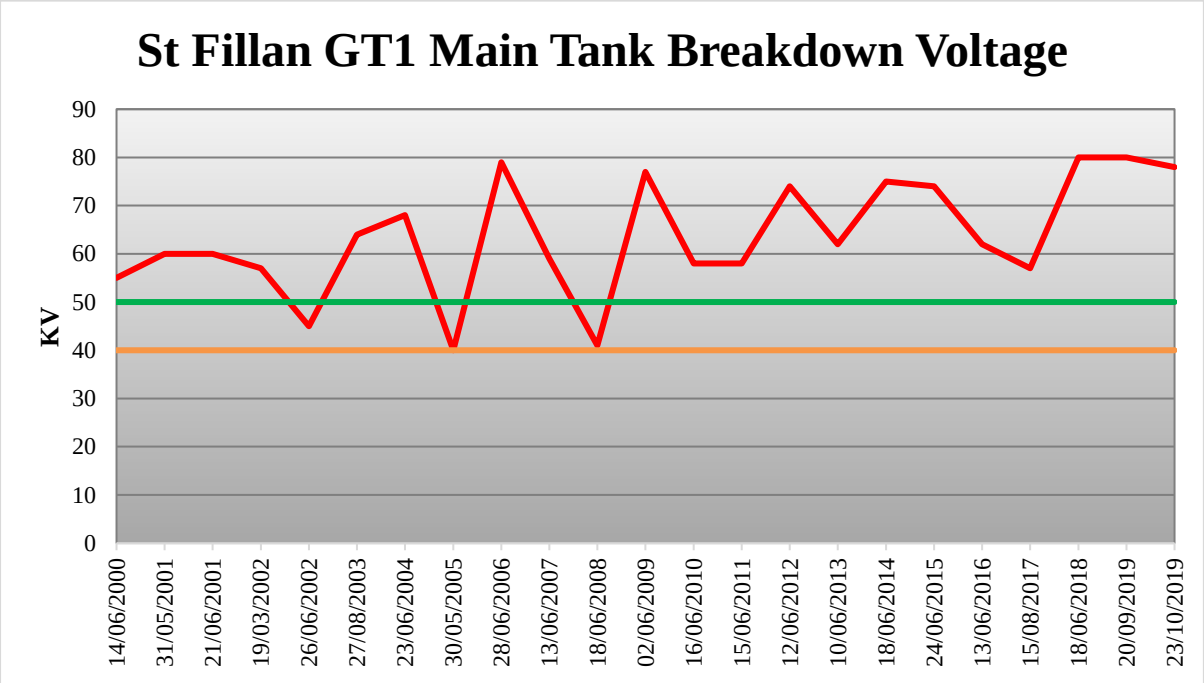


The historical moisture data spans 23 samples taken over the period of 2000 to 2019. Over the operational life of the transformer the moisture levels have been dynamic and have exhibited an increasing trend. Moisture results have predominantly been categorised as "Good", as detailed in IEC 60422 for category B apparatus. A total of 7 samples are categorised as "Fair". The peak value recorded in June 2009 was 25µl/l. The overall moisture trend is acceptable but would require reconditioning to restore the levels to a category of "Good" as defined in IEC 60422.

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**

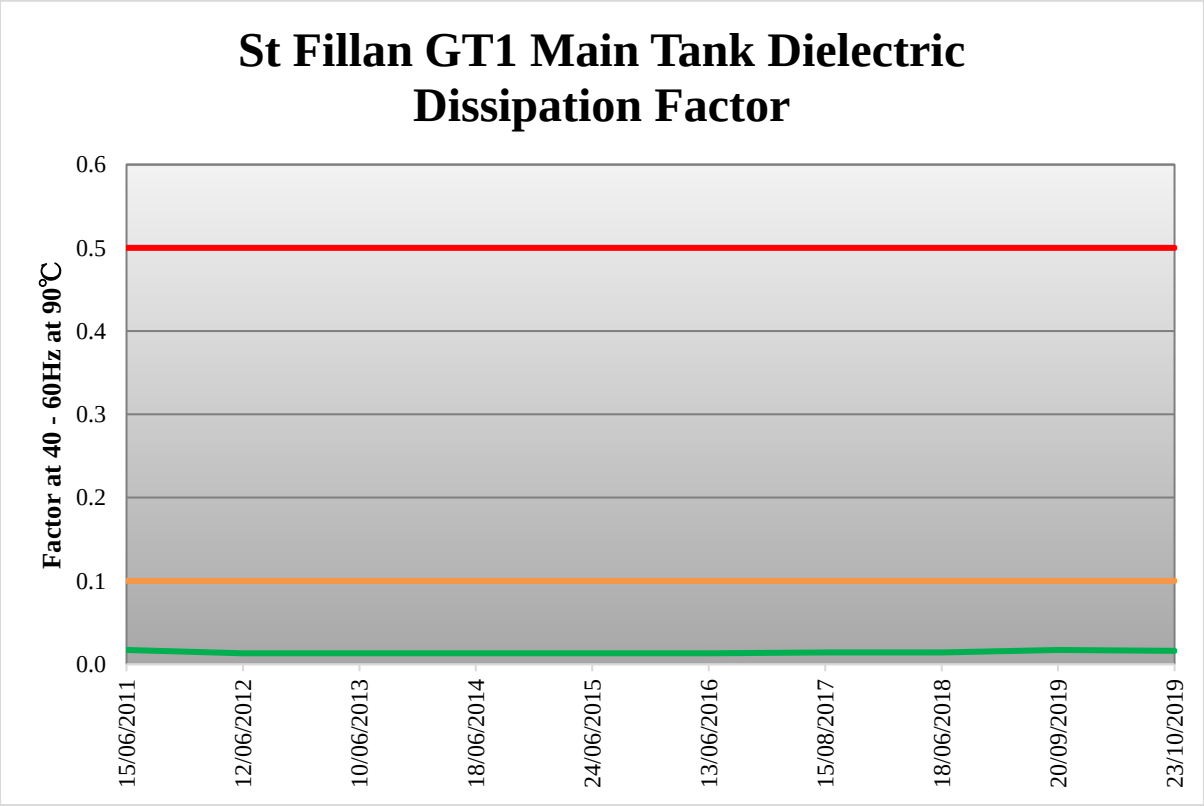


The historical breakdown voltage record spans the period of 2000 to 2019 and is inclusive of 23 samples. With the exception 3 samples from June 2002, May 2005 & June 2008 which are categorised as "Fair" as detailed in IEC 60422, all samples are "Good". Breakdown voltage levels are dynamic throughout the sample range yet display an overall increasing trend. No substantial correlation in reductions is breakdown voltage levels with increased moisture content of the main tank are observed. Overall, the breakdown voltage level trend is satisfactory.

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.

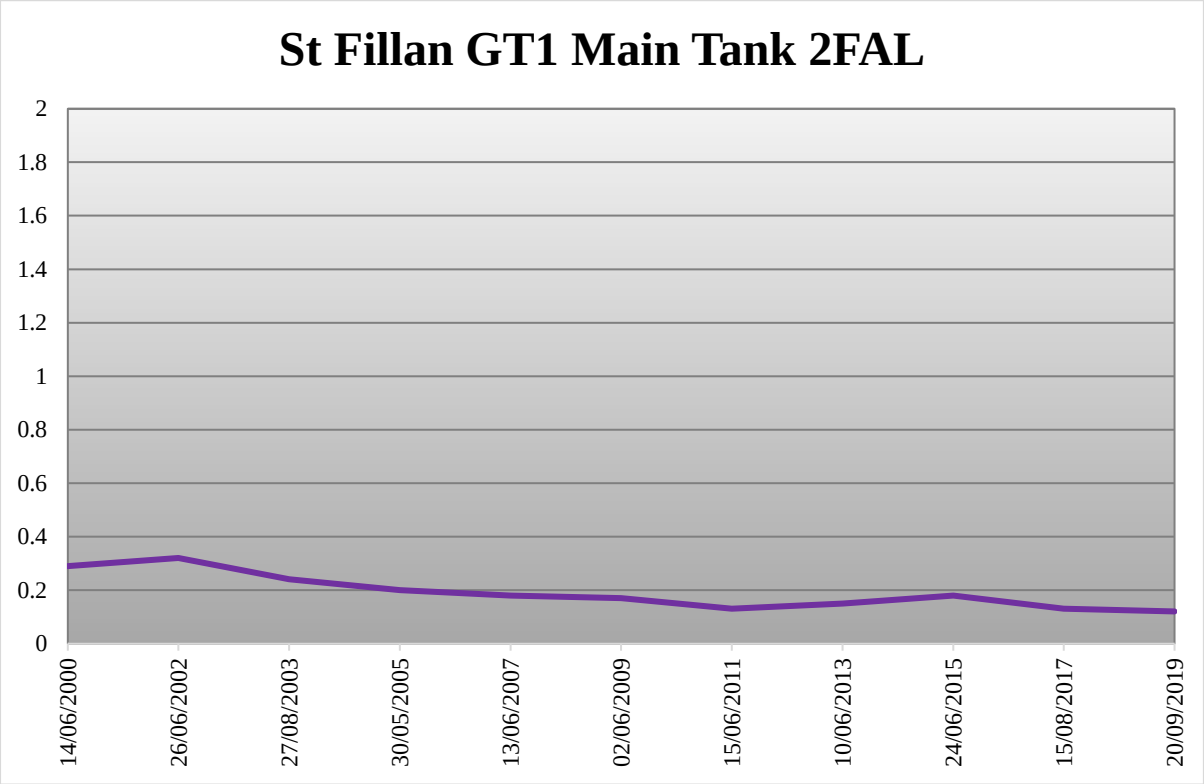
IEC 60422 "Category B" Limits for Dielectric Dissipation Factor	
Classification	**kV**
Good	**< 0.1**
Fair	**0.1 – 0.5**
Poor	**> 0.5**



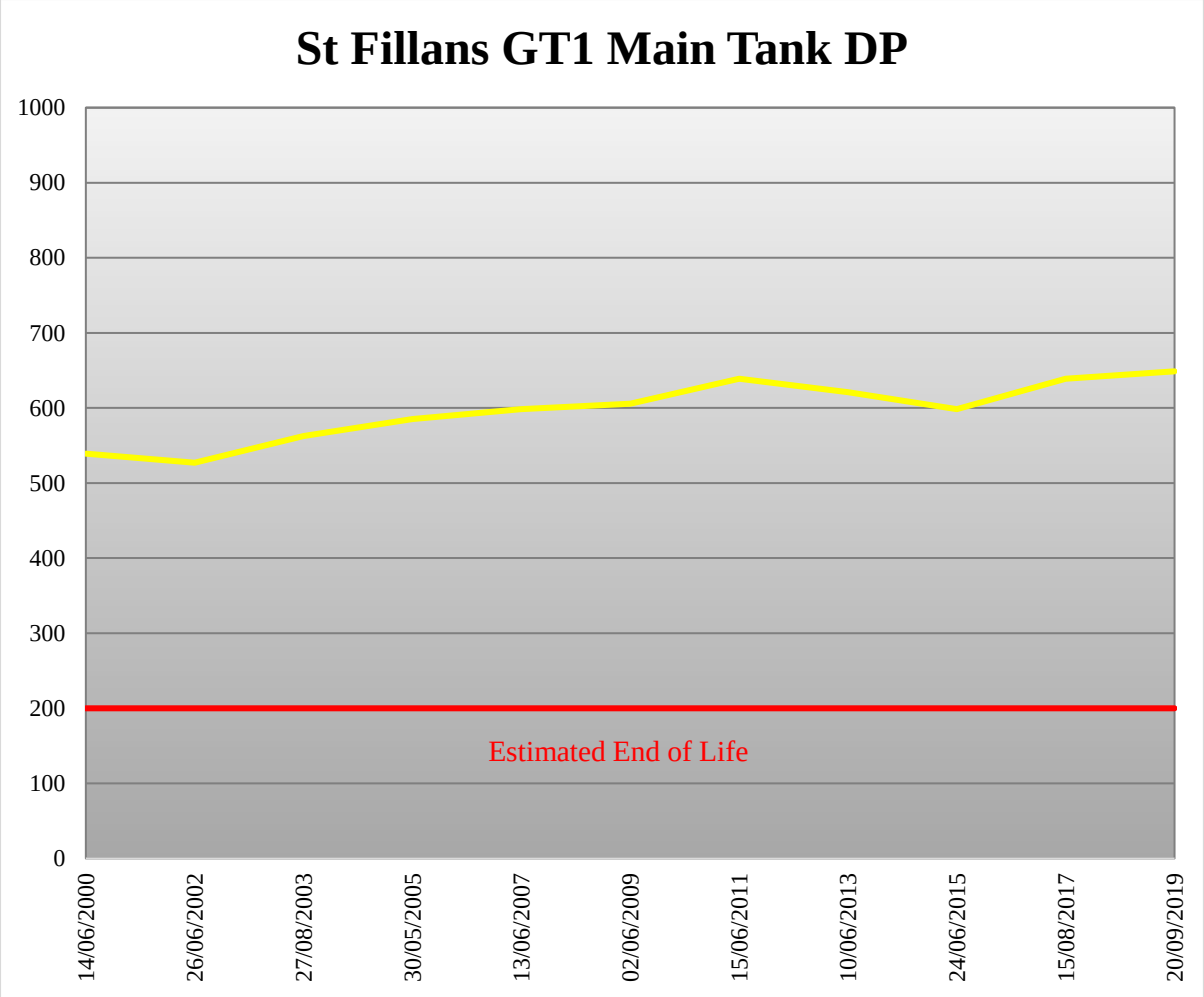
The dielectric dissipation factor trend is steady state and is constantly defined as "Good". This result is satisfactory.

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, and is therefore subjected **to high degree of uncertainty.**



The 2FAL record spans from 2000 until the most recent sample, which was taken in September 2019. The 2FAL characteristic exhibits a decreasing trend over the sample range, reductions in 2FAL levels are indicative of a dilution effect by means of top ups or oils system interventions. The final value recorded was 0.12 (Est DP 649), compared to the highest value recorded in the sampling period of 0.32 (Est DP 527). The link between measured 2FAL and estimated DP is reliant on an algorithmic relationship, of which there are five different variants. The Chengdong algorithm has been used to relate measured 2FAL to estimated DP. In order to estimate the DP of the insulation system, the highest value of measured 2FAL shall be used (From June 2002). 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 40% residual life remaining in the paper insulation. This suggests that the paper insulation is in an aged condition.


St Fillans GT1 Main Tank DP
1000
900
800
700
600
500
400
300
200
100
0
Estimated End of Life
14/06/2000
26/06/2002
27/08/2003
30/05/2005
13/06/2007
02/06/2009
15/06/2011
10/06/2013
24/06/2015
15/08/2017
20/09/2019

General

The following sections are made with reference to information contained within SSEN Report T2-EJP-0041, henceforth referred to as document.

Previous Condition Assessments

The iSIM inspection data for GT1 is categorised as level 2 (Apparent normal wear, intervention to be done in the next refurbishment). This highlights that no immediate intervention is required on GT1. Comment is also made that a 'major issue' for this transformer is the availability of spares. It is noted that this is one of the oldest transformers on the SHE Transmission network.

The tap changer is also recorded as category 2 (Apparent normal wear, intervention to be done in the next refurbishment).

Also, as detailed in document section 6.2, concerns are raised on the ability of the bund walls being capable of containing a significant oil leak. Oil leaks are also observed upon the cooler bank frame and below LV bushings. Absorbent cloth was also found within the bund, evidence of past oil leaks. These issues are particularly concerning due to the transformers proximity to Loch Earn and present driving environmental factors that should be addressed at the first opportunity.

Partial Discharge Survey

A partial discharge survey was conducted in November 2014 by Elimpus (Report: Greg Bialkowski "ST FILLANS 132kV AIS PD SURVEY,2014), with no indication of partial discharge being found. The level of possible partial discharge activity from transformer GT1 as evidenced by the presence of low levels of Hydrogen and Methane in the dissolved gas analysis would be undetectable by means other than DGA.

Infra-Red Thermovision Survey

An infra-red thermovision survey was conducted in 2016 & 2017 with no abnormalities found.

Impulse Protection

Unknown

Load & Duty Cycle

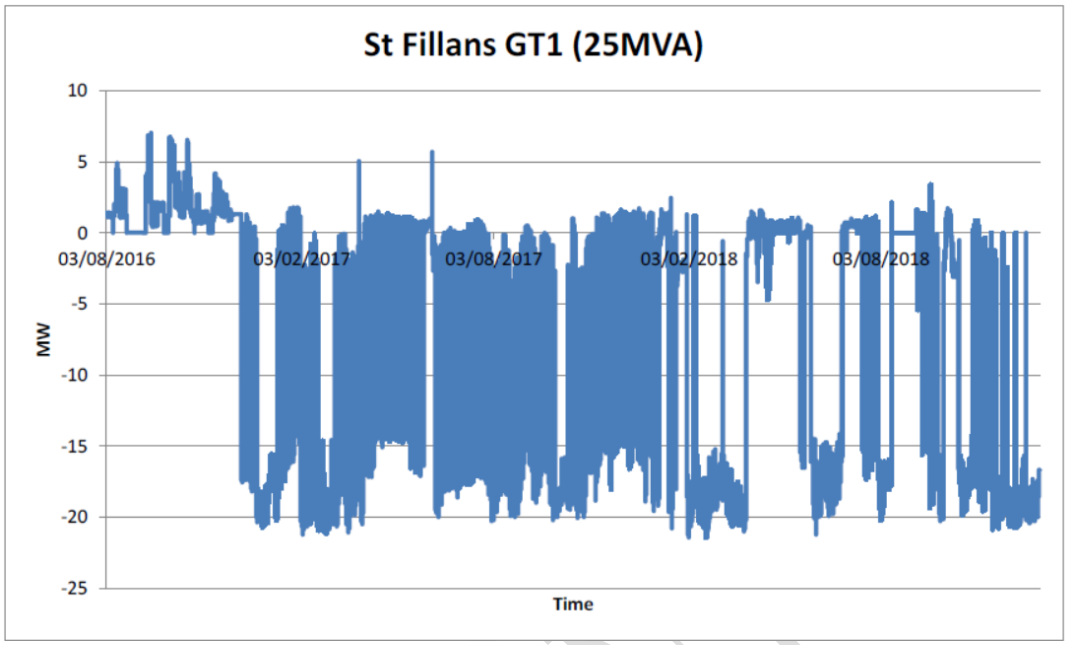


Figure 5.10 seen above, from document section 5.7, displays the load profile of GT1 for the period of August 2016 to December 2018. It should be noted that the negative values displayed are due to St Fillans Power Station being distribution connected. As seen from above, GT1 maximum loading is displayed as approximately 21MVA which is within the 25MVA ONAN rating of the transformer. This indicates that the transformer has no excessive loading. Based on historical oil data made available, no substantial reduction in life expectancy can be associated with the loading of transformer GT1.

Historical Faults

No faults have been recorded on transformer GT1.

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 - 31/07/2003

GT1TAP - MW 132kV Grid Transformer Tap changer maintenance - 15/12/2003

GT1 - MW 132kV Grid Transformer Maintenance - 15/06/2007

GT1TAP - MW 132kV Grid Transformer Tap changer maintenance - 15/06/2007

GT1 - MW 132kV Grid Transformer Maintenance - 17/08/2011

GT1TAP - MW 132kV Grid Transformer Tap changer maintenance - 17/08/2011

GT1 - MW 132kV Grid Transformer Maintenance - 29/05/2015

GT1TAP - MW 132kV Grid Transformer Tap changer maintenance - 29/05/2015

Conclusion

The iSIM inspection data for GT1 is categorised as level 2 (Apparent normal wear, intervention to be done in the next refurbishment). This highlights that no immediate intervention is required externally on GT1. Comment is also made that a 'major issue' for this transformer is the availability of spares. It is noted that this is one of the oldest transformers on the SHE Transmission network.

The tap changer is also recorded as category 2 (Apparent normal wear, intervention to be done in the next refurbishment).

Concerns have been raised on the capability of the bund walls to contain a significant oil leak. Oil leaks been observed originating from the cooler bank and below LV bushings. Absorbent cloth was also found within the bund which would suggest that the oil leaks have been present for some time. These issues are particularly concerning due to the transformers proximity to Loch Earn. It is considered that this transformer presents an environmental risk.

Analysis of the DGA shows no indication of discharge but there appears to be a thermal abnormality within the main tank, which is present over entire sample range. Dissolved ethylene should be kept under surveillance. There is a correlation between dissolved CO, methane, ethane & ethylene trends which suggests that the thermal abnormality is causing ageing of the paper insulation. It is considered that the dissolved methane is a residual effect of the dissolved ethylene, but there could be a contribution to this by a low level partial discharge, normally characterised by the presence of hydrogen and methane. If this partial discharge was to exist it would most likely be undetectable by other means due to the low level of activity.

The oil quality parameters for the main tank comprising of breakdown voltage and DDF are all categorised as "Good" as defined by IEC 60422:2013 indicating that the insulating oil has good dielectric properties. The acidity and moisture are categorised as "Fair" as defined by IEC 60422:2013 In order to restore the acidity and moisture content to the category of "Good" as defined by IEC 60422, the oil may require intervention. This should be kept under surveillance.

The highest value of measured 2FAL recorded (From June 2002) was measured as 0.32 which equates to an estimated DP of 527. 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 40% residual life remaining in the paper insulation. This suggests that the paper insulation is in an aged condition. As the historical estimated DP has exhibited a rising trend since 2002, it is evident that this has been due to dilution of

the main tank oil by means of top ups of new or reclaimed oil. This would render the estimated DP redundant as an ageing indicator, as what is presented by the oil analysis will be over optimistic in the true DP value.

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 appears to be in an aged condition

Recommendations

In order to further assess and manage the condition of this transformer, the following recommendations are made:

- Investigation into a lack of available spare parts. This should be thoroughly risk assessed with particular reference to the longevity of the transformer.
- Detailed inspection of the asset – outage required.
- 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.
- Inspection and assessment of the moisture management system.
- Following detailed inspection continue with routine inspection.
- Increase the oil sampling frequency to 6 months to keep the dissolved ethylene under surveillance.
- Continue with routine maintenance.
- Detailed load flow monitoring.
- Ongoing load flow monitoring