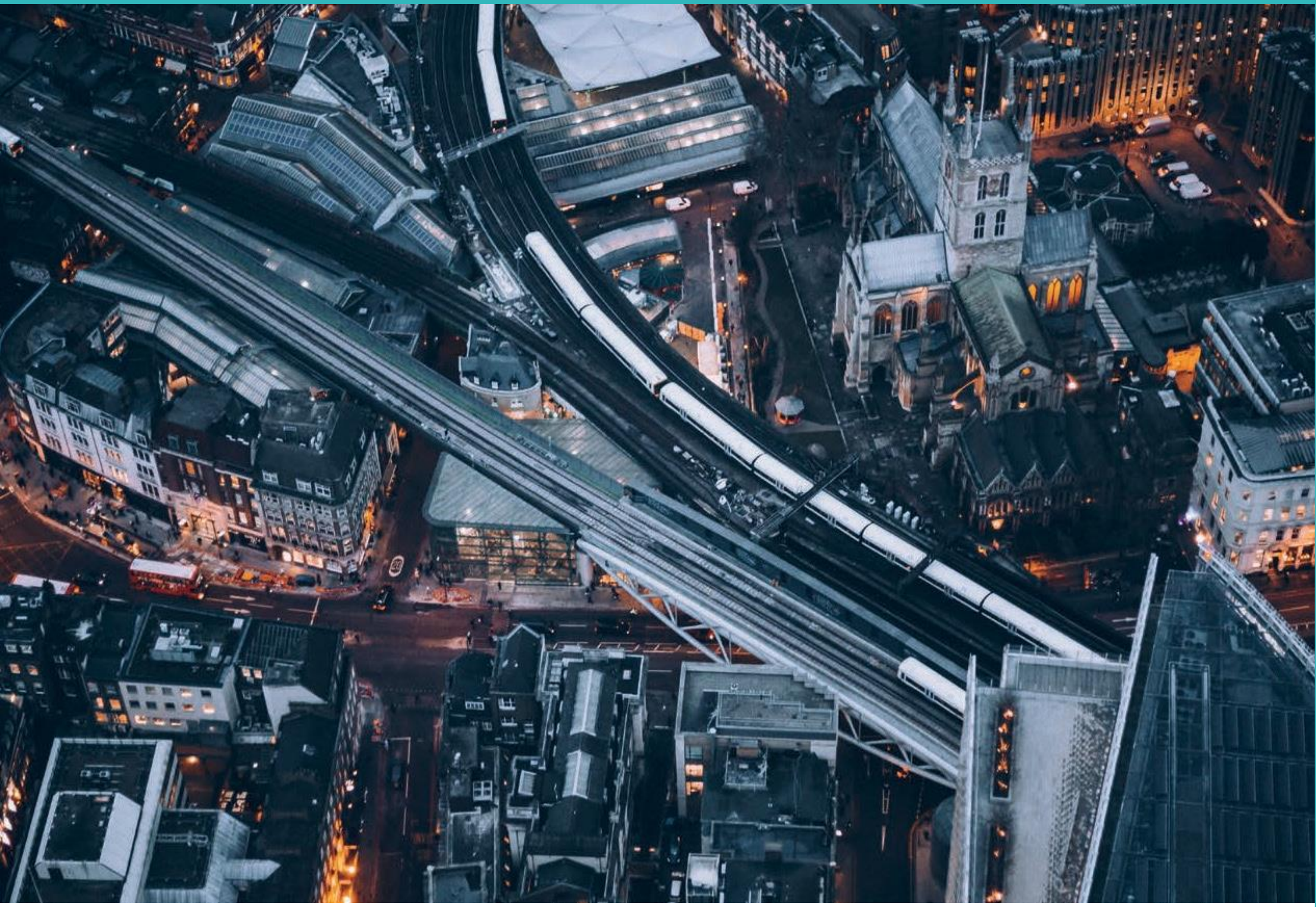

REPORT

Condition Assessment and Health Index of HV Assets at Location A

Prepared for: Company A

Report No: L0000.01
Document Version: Issue 1
Date: 15 April 2020

Version History

Date	Version	Author(s)	Notes
15/04/2020	Issue 1	Jonathan Lewin	Click to enter notes.

Final Approval

Approval Type	Date	Version	EA Technology Issue Authority
Final	15/04/2020	Issue 1	Anne McIntosh

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Summary

EA Technology has extensive experience of working with owners and operators of high voltage equipment to understand degradation and failure processes. Company A commissioned EA Technology to assess the condition of eight of their oil filled transformers located at the Location A site and derive and populate a health index (HI).

Conclusions

C1. None of the transformers were found to be at their end of life. Transformers 2, 4 and 8 were found to be approaching their end of life in approximately 8 years.

C2. All of the transformers were found to have a good oil quality indicating low moisture and acidity contents and acceptable breakdown voltage strengths with the exception of 4 which was found to have an elevated acidity content.

C3. The DGA for the transformers indicated they are performing satisfactorily, with no evidence of electrical degradation.

C4. The FFA for 2 and 8 indicated the presence of paper degradation. The condition of the paper insulation for the remaining transformers was acceptable with no evidence of significant degradation.

C5. The current condition of five of the transformers was found to be good with HI <4. Transformers 2, 4 and 8) were found to be in a moderate condition.

Recommendations

R1. On-going oil analysis and the application of EA Technology's health index are recommended for the transformer and switchgear population in order to monitor the rate of degradation and identify active management strategies.

R2. Transformer 4 should be re-sampled to monitor the acidity content which appears to be slowly advancing. The unit should be considered for remedial treatment to remove the oxidation product from the oil.

R3. The transformers should be re-sampled, and the health index recalculated in 12 months (October 2019) in accordance with maintenance practices.

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Appendices

1. Background and Introduction

EA Technology has extensive experience of working with owners and operators of high voltage equipment to understand degradation and failure processes. One aspect of this work has been the development of health indices for high voltage equipment which combine the available relevant asset information to derive a single number intended to provide an indication of overall degradation and proximity to end of life.

Company A commissioned EA Technology to assess the condition of eight of their oil filled transformers located at the Location A site and derive and populate a health index (HI). To facilitate this EA Technology undertook a sampling and test programme.

Previous work was carried out at the Location A site in 2014 and 2016 and the findings were reported in EA Technology reports A0611 and A2056 respectively.

This report details the findings for the eight latest transformer oil samples submitted for analysis.

2. EA Technology's Health Index

Working with many owners and operators of high voltage equipment, EA Technology has developed a process for deriving and populating health indices for a wide range of HV assets. The intention is to combine relevant information in order to provide a means of ranking equipment by proximity to end of life. The final number for each piece of equipment is normalised onto a scale of 0 to 10; 0 representing the best condition and 10 the worst condition. The detailed formulation of a health index for each population of equipment is specific to that population, based on the available condition information and the background history of the units in the population. The formulation is designed such that increasing values represent increasing levels of degradation and probability of failure (POF). However, this is not a linear scale. By design the relationship between the health index and the probability of failure is a cubic relationship. Individual items of equipment with a health index of <4 are in 'good' condition with a very low probability of failure, that would not be expected to deteriorate significantly in the short or medium term. Values in the 4-7 range indicate 'moderate condition' with a low current probability of failure, but at risk of significant deterioration in the medium term. Values >7 indicate 'poor' condition with a significantly increased probability of failure that will continue to increase relatively quickly in the short term.

In general terms assets in 'good' condition (HI <4) would be expected to continue to operate satisfactorily for the foreseeable future (to have a long remnant life) and do not require any significant change to existing operation and maintenance.

Assets in 'moderate' condition (HI 4-7) are not at immediate risk but may become increasingly unreliable in the medium term (5-10years). Assets in this condition are potentially candidates for life extension measures, enhanced maintenance, refurbishment etc.

Assets in 'poor' condition (HI >7) are at risk in the short term, this risk will increase relatively quickly. Significant investment (replacement) is required to prevent unacceptable probability of failure. For electricity network assets this is often effectively End of Life (EOL).

Having derived the initial health index, the HI in future years can also be estimated based on the understanding of the degradation processes and the rates at which these proceed. Definition of end of life for assets will vary depending on the application and operational considerations. However, the approach is based on identifying units where the probability of failure is significantly raised, i.e. those with a health index of greater than 7. The actual end of life, and therefore the remnant life, of an existing unit will depend on the level of risk acceptable to the owner. In the present case any transformer with a health index of greater than 7 would be deemed to be approaching end of life.

3. Transformer Degradation

3.1 Internal Degradation

Internal insulation degradation results from oxidation of the oil and paper components. The rate of degradation is very dependent upon the operating condition, in particular the temperature, and therefore the load. The rate of the oxidation processes increases exponentially with temperature and therefore a transformer that is heavily loaded for long periods of time will have a shorter life than a transformer that is subject to moderate loads. Occasional overload situations in which the temperature of the transformer may be raised above the normal maximum temperature cause particularly rapid degradation and therefore significantly shorten the transformer life.

The effects of internal oxidation can be sensitively and accurately monitored by oil tests. Oil test results provide information both on the degradation of the oil and the paper insulation. Measurement of moisture, acidity and breakdown strength of the oil directly indicate the condition of the oil, and also give an indication of the overall internal condition of the transformer. Moisture, acidity and solid contamination are products of the oxidation of the oil and the paper. Furthermore, moisture and acidity accelerate the ageing of both the oil and the paper. Therefore, the indication of poor oil quality is an early warning of overall degradation of the oil and paper insulation system. In addition, ensuring a satisfactory oil condition will assist in maintaining a safe and reliable transformer performance and prevent premature ageing of the paper insulation and therefore extend the life of the transformer.

The level of water in transformers is particularly significant. As indicated above, water is a product of the oxidation processes occurring internally but moisture could also originate outside the transformer and ingress via seals. The great majority of water in a transformer will be held in the paper not the oil as the solubility of water is approximately a thousand times greater in paper than oil. The relationship between water levels in oil and paper will vary significantly with temperature. It is therefore very important to measure the oil temperature at the time of sampling so that the water level can be properly interpreted.

A water level is therefore very significant as an indication of overall health of a transformer. Also, because >99% of the water in a transformer is in the paper removing water from the oil will have very little effect on the level of water in the transformer. For this reason short term filtration processes are of limited value.

The condition of the paper can be assessed by measuring the level of furfuraldehyde in the oil. Furfuraldehyde is a by-product of the oxidation process of the cellulose chains that make up paper. As this oxidation process proceeds, the average length of the cellulose chains decreases and the mechanical capability of the paper will also decrease. The level of furfuraldehyde in the oil approximately follows the decreasing cellulose chain length (degree of polymerisation DP). The DP of paper in a new transformer is approximately 1000. As the paper ages this DP reduces and the ultimate end of life for the transformer is when the paper has virtually no mechanical strength left and starts to break up and dissolve into the oil, DP approximately 250.

Dissolved gas analysis provides indication of abnormal electrical or thermal activity within a transformer. The energy available from overheating or electrical discharge breaks the oil down into the hydrocarbon gases which can be detected by analysis. The level and ratios of the different gases are a well-established means for detecting and identifying a developing internal fault.

By combining the information available from these different analyses a very good understanding of the internal condition of the transformer can be obtained.

3.2 External Degradation and Ancillary Components

Other than internal insulation condition, possible end of life conditions can occur as a result of external degradation (corrosion of tanks, pipe-work, cooling systems) or degradation and failure of ancillary components (tap changers, bushings, cable boxes etc.). External corrosion can be prevented by appropriate maintenance and is readily assessed by inspection.

4. Oil Results & Health Index Assessment

Information on the history and background of these transformers was provided by Company A and this has been used to determine the health index and EOL. This information is intended to enable a good understanding of the maintenance history, environment, loading history and likely future requirements, nature of load and any specific concerns. No new up to date information has been submitted.

Oil samples submitted by Company A have been subjected to a comprehensive set of analytical procedures designed to obtain optimum condition information. Three condition codes have been derived from the oil test results. These are derived from the measured values of moisture, acidity, breakdown strength, furfuraldehyde and DGA. The threshold levels for the different parameters have been established over many years of testing and assessing thousands of individual transformers.

The health index has been derived by combining the oil-based information with codes relating to load/age, environment, maintenance and operational history, external condition and ancillary component obtained from the information provided.

4.1 Summary of Oil Analysis Results

The most pertinent values (moisture, acidity, BDV, hydrocarbon gases and furfuraldehyde) that are the basis of the 3 condition codes used in the transformer health index are summarised in Table 1. In addition, recommendations for the future operation, testing interval and transformer management are given. The detailed transformer oil analysis is given in Appendix I.

Table 1 Summary of Transformer Oil Results

TX ID	Serial No.	Sample Date	H2 ppm	CH4 ppm	C2H6 ppm	C2H4 ppm	C2H2 ppm	Moisture ppm	BD Strength kV	Acidity mgKOH/g	FFA ppm	Est. DP	Comments	Sampling Interval
1	1	09/10/18	0	1.1	0	0.7	0	3.8	81.8	0.033	<0.005	1099	Transformer is operating satisfactorily repeat DGA in 12 months to monitor and trend. Acidity is acceptable and complies with IEC 60422. Moisture is acceptable and complies with IEC 60422. Breakdown voltage is acceptable and complies with IEC 60422. DGA is acceptable.	1 Year (Oct 19)
2	2	10/10/18	0	1.1	0	1.3	0	11.7	48.8	0.117	3.608	303	Transformer is operating satisfactorily repeat DGA in 12 months to monitor and trend. Acidity is acceptable and complies with IEC 60422. Moisture is acceptable and complies with IEC 60422. Breakdown voltage is acceptable and complies with IEC 60422.	Attention
3	3	09/10/18	0	1.3	0	0	0	10.1	54.9	0.064	<0.005	1099	Transformer is operating satisfactorily repeat DGA in 12 months to monitor and trend. Acidity is acceptable and complies with IEC 60422. Moisture is acceptable and complies with IEC 60422. Breakdown voltage is acceptable and complies with IEC 60422. DGA is acceptable.	1 Year (Oct 19)
4	4	09/10/18	6	3	0	2.8	0	10.0	40.9	0.282	0.056	807	Transformer is operating satisfactorily repeat DGA in 12 months to monitor and trend. The oil is slightly acidic and appears to be advancing, consider remedial treatment to remove oxidation products from the oil. Moisture is acceptable and complies with IEC 60422. Breakdown voltage is acceptable and complies with IEC 60422.	Attention

TX ID	Serial No.	Sample Date	H2 ppm	CH4 ppm	C2H6 ppm	C2H4 ppm	C2H2 ppm	Moisture ppm	BD Strength kV	Acidity mgKOH/g	FFA ppm	Est. DP	Comments	Sampling Interval
5	5	09/10/18	0	1.9	1.1	1.6	0	4.9	64.9	0.076	<0.005	1099	Transformer is operating satisfactorily repeat DGA in 12 months to monitor and trend. Acidity is acceptable and complies with IEC 60422. Moisture is acceptable and complies with IEC 60422. Breakdown voltage is acceptable and complies with IEC 60422. DGA is acceptable.	1 Year (Oct 19)
6	6	10/10/18	0	1.8	0	1.6	0	1.8	78.7	0.07	<0.005	1099	Transformer is operating satisfactorily repeat DGA in 12 months to monitor and trend. Acidity is acceptable and complies with IEC 60422. Moisture is acceptable and complies with IEC 60422. Breakdown voltage is acceptable and complies with IEC 60422. DGA is acceptable.	1 Year (Oct 19)
7	7	09/10/18	2.5	1.3	0.9	0.9	0	2.3	74.6	0.023	<0.005	1099	Transformer is operating satisfactorily repeat DGA in 12 months to monitor and trend. Acidity is acceptable and complies with IEC 60422. Moisture is acceptable and complies with IEC 60422. Breakdown voltage is acceptable and complies with IEC 60422. DGA is acceptable.	1 Year (Oct 19)
8	8	10/10/18	0	5.6	1.8	5.2	0	13.5	60.6	0.116	1.072	450	Transformer is operating satisfactorily repeat DGA in 12 months to monitor and trend. Acidity is acceptable and complies with IEC 60422. Moisture is acceptable and complies with IEC 60422. Breakdown voltage is acceptable and complies with IEC 60422.	Attention

H2 denotes Hydrogen, CH4 denotes Methane, C2H6 denotes Ethane, C2H4 denotes Ethylene, C2H2 denotes Acetylene, FFA denotes furfuraldehyde, DP denotes Degree of Polymerisation.

4.2 Transformer Health Index

Table 2 provides a summary of health index results for the transformers included in the work programme. The current and the ten year predicted health index and probability of failure (POF) was calculated. In addition, the current estimated end of life was also calculated.

Table 2 Calculated Health Index and Probability of Failure for Transformer Population

Tx ID	Serial No	Current Health Index	Current POF	Health Index Year 10	Year 10 POF	Estimated End of Life Years
1	1	1.9	0.0019	2.7	0.0032	34
2	2	5.8	0.0134	7.4	0.0241	8
3	3	3.5	0.0048	4.5	0.0081	26
4	4	5.0	0.0098	7.6	0.0256	8
5	5	1.6	0.0016	2.3	0.0025	40
6	6	1.7	0.0017	2.4	0.0027	38
7	7	2.5	0.0029	3.7	0.0054	27
8	8	5.7	0.0130	7.4	0.0241	8

The health index values are determined by the contributions from the oil test results, transformer age, operational considerations, environment and previous history.

As explained in section 2 a health index >7 indicates an asset in relatively poor condition, with an increasing POF that will rise relatively quickly. End of life can be defined as when the POF becomes unacceptable, for critical assets a conservative view would be expected. On this basis a health index of 7 is a reasonable definition of reaching EOL. This is consistent with a DP value of 250 being one definition of EOL. The ageing process then enables an estimate of time to EOL. The current and ten year health index profiles for the transformer population are shown in Figure 1 and Figure 2.

Figure 1 Current Health Index for Transformer Population

Figure 2 Ten Year Health Index for Transformer Population

5. Discussion

By applying the EA Technology methodology to the Health Index values it is possible to estimate future Health Index values and therefore to estimate the time to end-of-life (EOL) for each asset, where a Health Index of 7 is deemed to be end-of-life. For transformers the individual oil results with respect to the oil quality, DGA and FFA give a good indication of the overall condition of the transformer. Consequently, these results are significant in the health index calculations.

The transformer was found to have good oil quality indicating low moisture and acidity contents and high breakdown voltage strengths. The rate of oxidation of oil is dependent on several factors but the oil temperature is critical. As the temperature increases so does the rate of oxidation, which doubles for every 10˚C rise. Consequently, the rate of oil oxidation is dependent on such parameters as loading, ambient temperature and transformer cooling in addition to the chemical properties of the oil itself. Maintaining an acceptable oil quality within the transformer is critical to assist in managing the performance of the transformer and protecting the paper insulation against premature ageing.

The DGA for the transformer was found to be acceptable with no evidence of electrical degradation, this confirms there is currently no arcing activity present in the unit.

The FFA indicated no evidence of significant paper degradation. A DP of 200 to 250 is generally accepted to be at end of life for transformers; at this level the paper has lost the majority of its tensile strength. It should be noted that tap changers are not assessed for paper degradation.

The current condition of the transformer was found to be good (i.e. HI <4) and it is expected to remain in good condition for the next ten years (assuming stable operational conditions). On-going oil analysis and the application of HI in future years will assist in understanding the condition of the transformer and identify pro-active management strategies that will assist in extending the life of the transformer population and their continued safe and reliable operation.

The transformer was not found to be at or approaching its end of life (EOL). EOL is generally accepted to be when the condition of the transformer results in an unacceptable probability of failure. In the case of transformers this occurs when the paper insulation has little mechanical strength left (DP ~250). Such transformers are at increased risk of failure, particularly if subjected to mechanical stress, including those generated during a through fault.

Regarding the transformer sampling interval, EA Technology normally recommends a maximum of 12 months for units showing no indication of performance issues. Shorter times of 6 months (as in the case for this transformer), 3 months or immediate retest are used when fault gases are detected and depend on the severity of indicated fault. A 12-month sampling interval is used as it enables the transformer's performance to be monitored and will ensure most faults are identified before significant damage to the transformer or performance issues arise. Where oil quality issues are identified an Attention or Immediate Action status is given depending on the severity of the oil condition.

6. Conclusions

C1. None of the transformers were found to be at their end of life. Transformers 2, 4 and 8 were found to be approaching their end of life in approximately 8 years.

C2. All of the transformers were found to have a good oil quality indicating low moisture and acidity contents and acceptable breakdown voltage strengths with the exception of 4 which was found to have an elevated acidity content.

C3. The DGA for the transformers indicated they are performing satisfactorily, with no evidence of electrical degradation.

C4. The FFA for 2 and 8 indicated the presence of paper degradation. The condition of the paper insulation for the remaining transformers was acceptable with no evidence of significant degradation.

C5. The current condition of five of the transformers was found to be good with HI <4. Transformers 2, 4 and 8) were found to be in a moderate condition.

7. Recommendations

R1. On-going oil analysis and the application of EA Technology's health index are recommended for the transformer and switchgear population in order to monitor the rate of degradation and identify active management strategies.

R2. Transformer 4 should be re-sampled to monitor the acidity content which appears to be slowly advancing. The unit should be considered for remedial treatment to remove the oxidation product from the oil.

R3. The transformers should be re-sampled, and the health index recalculated in 12 months (October 2019) in accordance with maintenance practices.

Appendix I Transformer Oil Diagnostic Data Sheets

Safer, Stronger, Smarter Networks

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