UTILIZING ON-LINE GAS ANALYSER TO DETECT GASSING TRANSFORMER IN A DISTRIBUTION SUBSTATION

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Abstract: The stability of any distribution network is very much depending on the performance of the power transformers. These transformers need to be monitored to ensure that any unwanted conditions, including high levels of certain gasses, are detected. These transformers are normally placed inside a transformer tank with mineral oil inside. The oil acts as insulation as well as coolant for the transformer windings. It is very important to monitor the levels of different gasses within the transformer tank as it may be harmful to the transformer and can cause malfunctions. This paper discuss the application of gas analysers, the detection of unwanted gasses and the possible causes of these unwanted high level of certain gasses. The gas sensors that form part of the analyser are located inside the transformer main oil tank.

Key words: Power transformer; On-line monitoring; Gassing

1. INTRODUCTION

The power distribution network in South Africa is currently under pressure to deliver enough power to industry. The maintenance of the grid, including the transformers are falling behind and thus unplanned outages may occur due to the pressure on the distribution network. The power utilities need to minimize or even eliminate load shedding and this can start by managing the demand profile. This will enable the utilities to shift loads and control the distribution to enable stable power over the distribution networks.

All power transformers need to be operational to assist utilities in in managing the network and to reduce the possibility of load shedding. Condition Based Maintenance (CBM) is an important strategy in asset management that would allow a transformer to operate according to its actual rated efficiency. Better transformer management could be achieved with online monitoring, routine diagnostics and CBM [1]. The basic construction of a power transformer is shown in Figure 1.

Figure 1: Power transformer construction [2]

The core and windings of the power transformer are fully immersed in transformer oil. The oil acts as insulator and coolant in preventing direct contact with atmospheric conditions. In specific the cellulose paper insulation of the windings, which is susceptible to oxidation.

All degradation and ageing processes of the oil-paper insulation produce gases. The most important transformer fault gases are H_2, CO, CO_2, CH_4, C_2H_2, C_2H_4 and C_2H_6. These gases are dissolved in the oil and if a certain level is exceeded gas bubbles arise. These bubbles can be transported into regions with high electrical stresses and will lead to Partial Discharge (PD) activities. At present, the Dissolved Gas-in-Oil Analysis (DGA) is one of the most important and most effective methods for transformer diagnostics of important parameters [3].

This paper will show how on-line gas analysers utilizing gas sensors assist in detecting an abnormal gassing transformer in a substation and contribute towards finding the source of the problem in the transformer. The paper is organized as follow: Section 2 discuss transformer gassing while Section 3 is concerned with the abnormal gassing of a transformer and in particular the reason for the abnormal gassing. Section 4 concludes the paper.

2. TRANSFORMER GASSING

The question is raised why is it important to do on-line condition monitoring on a power transformer and then in particular why to monitor the gasses within the transformer. On-line condition monitoring is there to provide information that can be utilized to predict the remaining life expectancy of power transformers. This is achieved by monitoring the health of a power transformer continuously in order to reduce a high failure rate. The on-line condition monitoring offers measurement analysis for most of the important parameters of the transformer condition. The following groups of operating parameters can be monitored continuously:

- Fans
- On load tap changer
- Transformer operating temperatures
- Dissolved gas analysis
- Transformer life cycle management and computed values
- Bushings

The advantages of on-line condition monitoring can be summarized by:

- Comprehensive picture of the current status, operating trends and signals received from your transformers,
- Faults can be detected early and correct decisions can be taken on a safe basis,
- Information for the economical use of maintenance measures to extend the service life,
- Opens the possibility for extending the operating time of power transformers,
- Reduces the risk of expensive failures,
- Provides potential in changing the maintenance strategy,
- Provides help and guidance on indicating the type of fault in the transformers and
- The advantage of prediction of transformer failure before it happens

Figure 2 below shows how rapidly and in this case within two days, the condition of a power transformer can deteriorate. Power transformers can get critical unexpectedly and has a major influence on the maintenance as well as the budget control, not even mentioning the problem if the transformer fails unexpectedly. The figure below shows that within two days the dissolved gasses reach critical levels and if it was not monitored this could have led to failure of the supply network and damage to the power transformer.

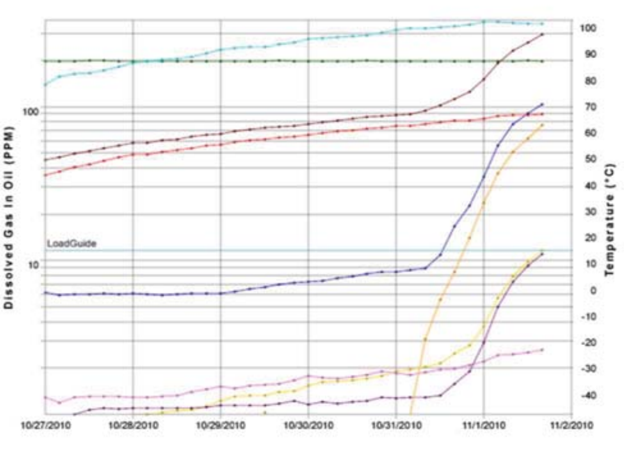

Figure 2: Dissolved gas within active transformer

On-line gas analysis thus provides a constant update of the gasses that are dissolved by the transformer oil within an active power transformer. This is often refer to as the blood test for transformers. It allows the user to have an accurate trend of the transformer oil condition in real time. This will then allow the user to do DGA that can trigger alarms when the gasses reach certain critical levels.

2.1 Gassing Guidelines

Amounts of gasses can be generated in a transformer tank with no real fault conditions caused by chemical processes at normal operating conditions in the transformer. This phenomenon is called "stray gassing" and can occur in new and newly repaired transformers and normally occur before the transformer is energized. [3]. The IEC 60599-2007 [4] give guidelines on how the concentrations of dissolved gases and stray gasses may be interpreted. These guidelines will assist in the diagnoses of the health condition of these power transformers.

Figure 3 below shows how gases begin to form at specific temperatures as well as dissolving in the insulation oil of an active power transformer [2]. This chart can be used for initial assessment of the dissolved gasses of new or recently repaired transformers [2]. The measurement of dissolved gasses assist with the knowledge on the type, complexity and seriousness of the situation within the transformer. Each gas, its concentration and its rate of change over a time period tell something about the nature and severity of the fault condition.

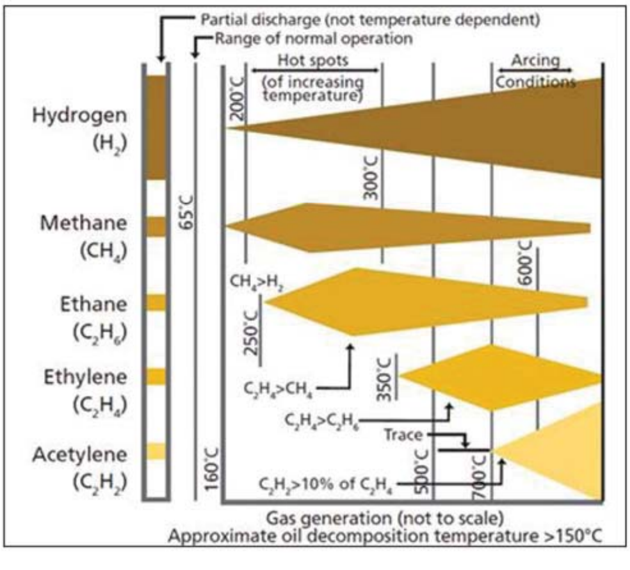

Figure 3: Gas generation chart [2]

2.2 On-line Gas Analysers

On account of deregulation of electricity generation and ageing of power transformers, there is an increasing concern to assess operating conditions of power transformers. In a role of the most acknowledged fault diagnostic method has DGA been widely applied for detection of incipient or potential faults, and thus for assessment of transformer condition [5]. Within an effective oil analysis program, oil sampling, sample storage, analysis and interpretation techniques play significant roles to ensure reliable diagnosis of oil-filled power transformer [6].

On-line gas analysers were installed at a distribution substation on several power transformers. One particular transformer was a newly installed 80 MVA power transformer. This was then incorporated into an active on-line condition monitoring system that produce warnings and fault condition messages once dangerous and faulty conditions occur within any linked transformer. The installed gas analysers were Kelman Transfix 1.6E transformer gas analyser from GE Energy. Figure 4 shows a Kelman Transfix transformer gas analysers installed at a power transformer.

Figure 4: A gas analyzers installed in transformer [11]

The recommended gas limits in transformer oil are regulated by the IEC 60599:2007 standard [4] for typical rates of gas increase for power transformers in ml/day. The recommended gas limits for new oil is shown in Table 1 below.

Table 1: Recommended gas in oil limits [4]

Gas	Symbol	Detected new oil (vpm)
Hydrogen	H_2	Non Detectable
Oxygen	O_2	< 10000
Nitrogen	N_2	< 30000
Methane	CH_4	Non Detectable
Carbon Monoxide	CO	Non Detectable
Carbon Dioxide	CO_2	< 150
Ethylene	C_2H_4	Non Detectable
Ethane	C_2H_6	Non Detectable
Acetylene	C_2H_2	Non Detectable

3. ABNORMAL GASSING PATTERN

The on-line gas analyser installed on the new 80MVA transformer mentioned earlier started to record abnormal gassing patterns. Oil samples were taken manually by the transformer supplier and the test samples were evaluated in a transformer oil testing laboratory. It was noticed that the transformer under test showed infant stages of combustible gasses being produced when the transformer was energized. This caused reaction and the relevant data gathered will be discussed in the next sections.

3.1 Transformer data from analyser sensor

Historical data for the last five months was retrieved from the gas analyzer and is shown in Figure 5. It was noticed that some abnormal gas levels was present. Subsequently more detailed data was retrieved from the analyzer and is depicted in Figure 6.

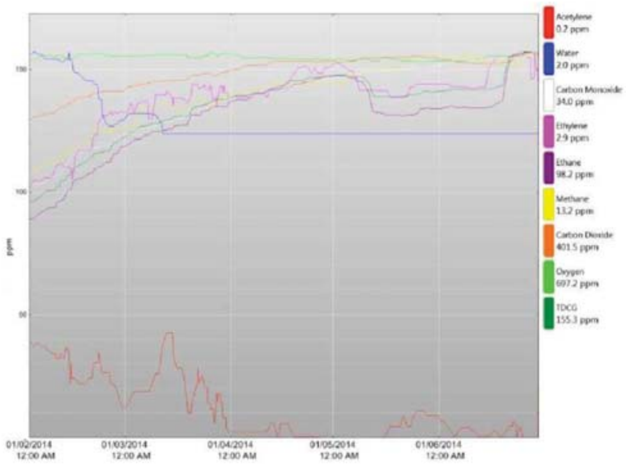

Figure 5: On-line gas analyser snapshot

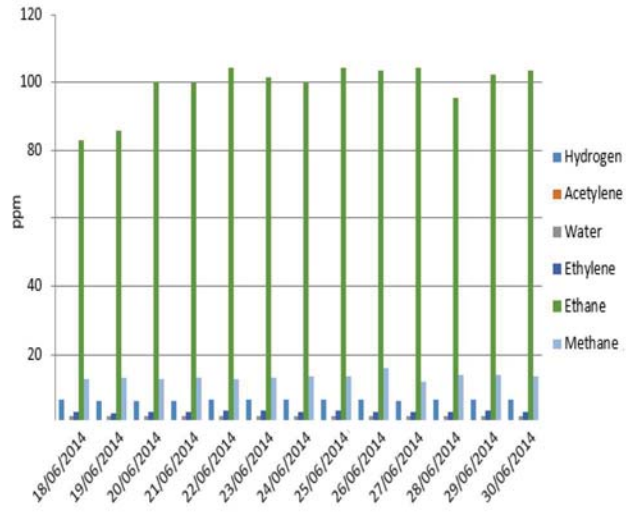

Figure 6: On-line gas analyser detailed data

The typical rates of gas increase for power transformers according to the IEC 50669:2007 [4] are shown in Table 2 together with the data retrieved for the specific transformer. The DGA of the transformer show a fairly low H2 with an abnormal elevated C2H6 result. This does not indicate typical transformer electrical or thermal faults. The transformer was then degassed over a four day period and oil samples were taken using gas tight syringes before and after de-gassing of the transformer whilst being de-energized.

Table 2: Results of DGA for transformer under testing

Number of days	103	Oil Quantity	33509 litres	
Gas	(Date 2) 2015/03/03	(Date 1) 2014/11/20	Production ml/day	Typical Rates Gas Increase ml/day
H_2	0	0	0.000	<5
CH_4	14	0	4.555	<2
C_2H_6	35	19	5.205	<2
C_2H_4	0	0	0.000	<2
C_2H_2	0	0	0.000	<0.1
CO	28	1	8.784	<50
CO_2	399	243	50.751	<200

The results were compared using the guidelines of the typical behaviour of 90% of power transformers as published in IEC 60599:2007 [4]. It is evident that the transformer's dissolved gas content correspond to a normal behaviour pattern after the de-gassing process was completed. The results of the DGA showing the results before, at and after de-gassing is shown in Table 3. The PTT LAB in Table 3 refer to the transformer manufacturer's transformer testing laboratory.

Table 3: Results of dissolved gas analysis

	Gas Detected in Sample (µl/l)						IEC 60599:2007 90 % Typical Quantities
	2014-04-15 PTT Lab	2014-05-08 PTT Lab	2014-06-11 Pre Degassing	2014-09-09 PTT Lab	2014-11-20 PTT Lab	2015-03-03 PTT Lab	
H_2	10	8	0	0	0	0	60 to 150
O_2	2424	3795	10054	5017	5099	3447	-
N_2	17283	19968	32855	11959	14492	12857	-
CO	52	48	25	1	1	28	540 to 900
CO_2	476	479	428	167	243	399	5100 to 13000
CH_4	21	19	0	0	0	14	40 to 110
C_2H_6	72	68	57	34	19	35	50 to 90
C_2H_4	2	2	0	0	0	0	60 to 280
C_2H_2	0	0	0	0	0	0	3 to 50
TDCG	157	145	82	35	20	77	< 500

The Total Dissolved Combustible Gasses (TDCG) according to IEEE C57.104-2008 [7] standard are indicated in Table 4. TDCG is equal to the sum of the Hydrogen, Carbon Monoxide, Methane, Ethane, Ethylene and Acetylene. This method of using the TDCG is an IEEE developed standard and covers not only the determination of a fault severity and its nature, but also offers some indication to the follow-up action that is necessary.

Table 4: Transformer gas surveillance guide [7]

Parameter	Measured Value ($\mu l_{gas}/l_{oil}$)	Evaluation Criteria		
		Normal	Caution	Warning
H_2	0	<100	100-700	>700
CH_4	14	<120	120-400	>400
C_2H_6	35	<65	65-100	>100
C_2H_4	0	<50	50-100	>100
C_2H_2	0	<2	2-5	>5
CO	28	<350	350-570	>570
TCDG	77	<700	700-1900	>1900

The data in Figure 7 depict the values of the different gas concentration recorded before and after de-gassing of the transformer. It is showing that the transformer results after the de-gassing initially indicate normally gassing pattern. It also indicate the increase in Ethane levels after a period after the de-gassing was done indicating that it was not related to the initial stray gassing found in new transformers.

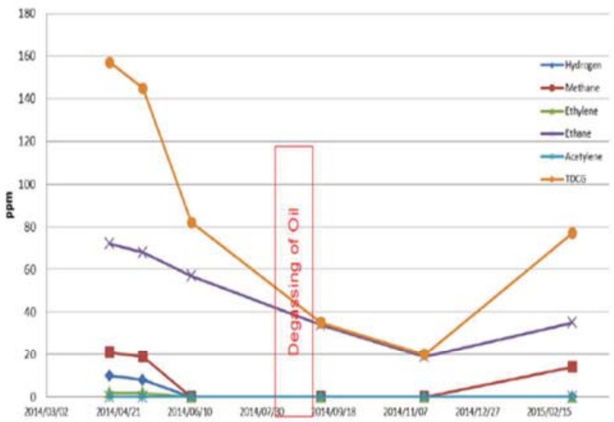

Figure 7: Dissolved gas concentration

3.2 Possible root causes of abnormal gassing

Transformer radiators forms a critical part of the cooling system of a transformer; thus the oil is permanently in contact with the inner surface of the radiators. The final steps of manufacturing radiators entails that, paint (red oxide) is flushed through the radiator. This is done for two main reasons. The first reason is to entrap any loose debris that might be left after the manufacturing of the radiators and the second reason being to cover any bare metal that is exposed within the inside surface, against rust. After the paint is drained through natural gravity, hot air is passed through the radiator to cure the paint. It is thereafter sealed prior to storage or transport to the place of installation.

It has been established in experimental analysis at the transformer provider's oil test laboratory that uncured paint will cause unnatural gassing when in contact with transformer oil. Elevated levels of Ethane, Carbon Dioxide, Methane and Hydrogen have been observed. The results for the oil compatibility test performed on uncured red oxide paint are shown in Table 5. The uncured paint does have a negative impact on the gassing of the oil and is not compatible with the insulating oil.

Hydrogen content can be directly connected to the painting and acid preparation of radiators. Based on the results after de-gassing the transformer at the distribution substation, the levels of the combustible gasses are well below typical concentration levels given in IEC 60599:2007 [4].

Table 5: Results of oil compatibility with red oxide paint

Component Name	*Reference oil*	*Paint/Oil Sample*
Hydrogen	360	567
Oxygen	16176	34008
Nitrogen	231069	325783
Methane	128	232
Carbon Monoxide	583	655
Carbon dioxide	574	1142
Acetylene	0	0
Ethylene	5	7
Ethane	56	172

Ethane and Methane are still present but not supported by other hydrocarbon gases, nor Hydrogen at this stage. The origin of Ethane and Methane generated after the degassing is gas trapped within the cellulose and core steel laminations. It must be emphasized that during oil filtration (de-gassing) sufficient passes were made to ensure that the more highly soluble gases are removed from the oil and cellulose insulation. The transformer was monitored closely after the de-gassing process.

The specific objective was to establish whether, based on historical evidence, a failure could have been predicted prior to a power transformer failure based on the practice of online condition monitoring technique utilising gas sensors. The transformer provider distribution network operates a variety of high voltage equipment with the main goal of supplying electricity continuously by means of an interconnected grid. Transformers are the most expensive pieces of equipment in the substation and require a specialized skill to ensure optimal utilization within their lifespan.

4. CONCLUSION

The use of gas sensors as part of a transformer gas analyser has proof to be effective in detecting abnormal levels of unwanted gasses within a transformer tank. It was also shown how retrieved historical data from the analyser was utilized to establish the possible root cause for the abnormal high gassing of the transformer. Although the manufacturer claimed that it was stray gasses because the transformer is new, the producing of stray gasses need to settle at some point. The problem did seem to be solved when the transformer was de-gassed but the results after the de-gassing as well as recent downloaded data indicate that the level of Ethane gas is still increasing.

The monitoring of the transformer is continuing to establish if other parameters have an influence on the gas levels or if it is the continuing problem created by the reaction between the transformer oil and the uncured red oxide paint alone.

ACKNOWLEDGMENT

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