Experiences of Continuous DGA Monitoring on a Faulty Transformer.

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Abstract: A transformer was found to be developing a thermal fault during fall 2004. Conditions deteriorated during spring 2005 and it was recommended to take the transformer out of operation for repair in May 2005.

Due to production requirements it was necessay to keep the transformer in operation until a planned outage and still have the transformer in a repairable condition. These requirements are normally difficult to fulfill but it was decided to monitor the transformer gas evolution on an hourly basis using an on-line monitoring unit.

This would enable the owner to stop the transformer before catastrophic failure propagation (run-away). On the same time it was decided to decrease the load to decrease risks.

The monitoring procedure has produced a number of new insights/ verified that a faulty transformer behaves in a specific manner. Some aspects of the facts obtained in this monitoring procedure are given in this paper.

Key words: on line monitoring, DGA, gas formation rate, fault.

Problem Description.

A transformer at a hydro-electric power plant gave strong signals of thermal fault and gas content was rising continually.

The transformer was required to remain in production until a given date but normal DGA trending presented alarming data indicating catastrophic failure to appear soon.

Continuous monitoring using a device that presented gas concentrations for all fault gases was seen as a solution enabling the discontinuation of operation when fault propagation appeared.

Relevant Transformer Data.

Year of manufacture: 1987

Power rating 90 MVA

Voltage: 18 kV / 410 kV

Sealed, cooling: OFAF, oil- weight: 33 tons.

Oil type: naphthenic medium refined, inhibited.

Relevant On-line Monitor Data.

The monitoring device chosen was selected due to accuracy and flexibility: It performed 1 DGA per hour using Head Space technique combined with a PAS detector (Photo Acoustic Sensor) and selective detectors for hydrogen and oxygen.

The unit sent alarm signals if given warning levels or gas concentration change rates were surpassed.

Initial Transformer Condition Assessment.

The total condition of the transformer was assessed using an extensive oil diagnostic program with the following data produced.

Oil:

Antioxidant BHT [GC] (mg/ kg)	**3130**
Total Acid Number [Pot] (mg KOH/ g)	**0.01**
Peroxides (mg/kg as H_2O_2)	**< 0.1**
Tan δ @90 ºCelsius.	**0.0149**
El Br Voltage (kV/ 2.5mm)	**75**
Inter Phase Tension (mN/ m)	**38**
Water content [KF] (mg/kg)	**< 5**
Water saturation (%)	**4.4**
Diss´d Oxid.. Prod. [ASTM D6802] (A)	**7.9**
Copper Cu [ICP] (mg/kg)	**5.8**
Corrosive Sulphur (mg/kg)	**1.2**
Total Sulphur (mg/kg)	**1320**

The conclusion was that the oil is as new (which is expected for a sealed and tight transformer where the antioxidant is not needed to take care of radicals induced due to internals oxygen exposure).

There are two parameters which are abnormal: *Corrosive Sulphur* and *Copper* in oil. Both are extremely high but were at the time not considered to be involved in the fault indication.

At the time of this writing it is not known to the authors if this was a correct assessment.

DGA [Toepler](ppm vol@NTP)

Hydrogen H_2	150
Oxygen O_2	1510
Nitrogen N_2	18900
Methane CH_4	725
Carbon monoxide CO	142
Carbon dioxide CO_2	2055
Ethylene C_2H_4	570
Ethane C_2H_6	310
Acetylen C_2H_2	0.2
Carbonyle sulfide COS	0.3

The assessment was *thermal fault with no cellulose involved* probably involving the core.

Following this assessment several DGA´s were taken and a rapid fault development was recorded. It was therefore recommended to take this transformer out of operation as a fault run-away could be expected anytime.

Due to energy shortage this was not ideal for the owner and alternative solutions were sought. As the transformer location was such that sampling logistics was a major problem it was suggested that a unit for continuous monitoring of fault gas evolution be mounted on the transformer for the remaining period until an outage was scheduled to take place.

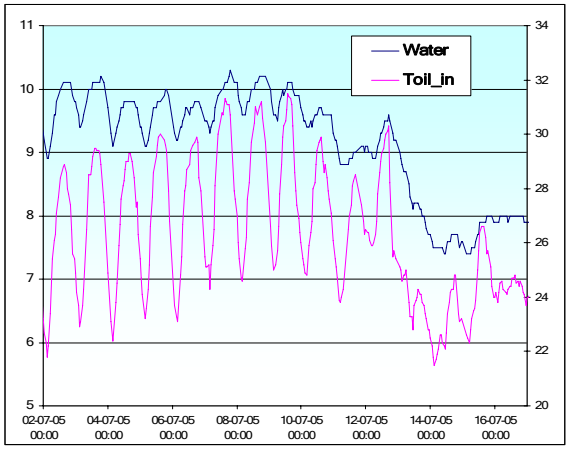
The purpose of monitoring was to allow the transformers´ continued operation without sacrificing safety and avoiding catastrophic failure.

The transformer was kept in operation for 6 weeks and the monitoring worked well after the initial period when gas production was employed as means for alarms setting and abandoned for the use of gas concentration limits.

Results: water.

It is well known that water has a strong and winding temperature depending tendency to migrate between oil-phase and cellulose-phase. This is due to its preference to remain in cellulose which leads to a water concentration level in cellulose that is mostly 1000 times higher than in the oil phase.

The graphical representation of results shows very clearly the migration of water between the phases.



In this case the oil temperature is measured at the sensor inlet which was located some 5 meters from the transformer sample outlet point and the data can therefore not be used to assess the transformer cellulose moisture level.

Fault gases, ethylene and ethane.

Ethylene and ethane are both hydrocarbon molecules and are non-polar and are therefore not as soluble in cellulose as water is.

In fact they can be seen as the inverse to water in the solubility aspect: very little soluble in cellulose and very soluble in oil.

In this particular case the level of ethylene and ethane were measured to be 980 ppm and 505 respectively.

The daily variation (high-low) readings were

- C_2H_4 Ethylene: 25-35 ppm.
- C_2H_6 Ethane: 20-35 ppm.

Annual gas concentration change.

If this were to be due to a true production of gas this would amount to concentration change of 7300 ppm/year to 12775 ppm/year.

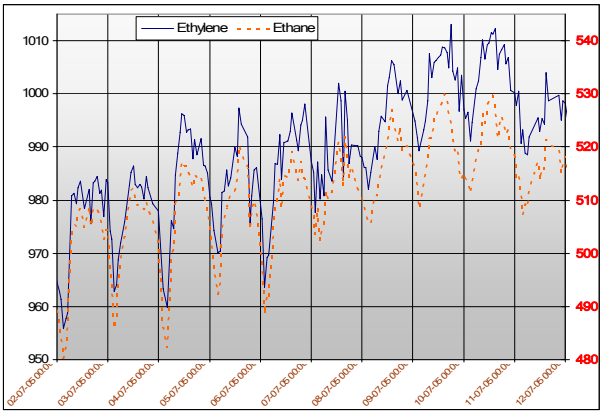
Apparent daily gas production rate.

Apparent gas formation rate is the rate calculated based on the lowest and highest measured concentration measured over the day.

In gas production terms (for this particular transformer):

- C_2H_4 Ethylene: 925-1295 ml/day.

- C_2H_6 Ethane: 730-1295 ml/day.



Evaluation of these data, using available methods, indicates a massive fault: gas production rate in excess of 100 ml per day is the lower limit for defined fault production.

True vs. Apparent gas production.

It is quite apparent that the above example does not signify the true fingerprint (size) of the fault but is instead due to the migration of gases between the two phases inside the transformer.

The example makes visible the problem of sampling a transformer of very high gas concentrations in which the migration of gases between oil and cellulose phases cannot be neglected. It shows how important it is to take samples under likeworthy operating conditions IF the transformer has very high contents of hydrocarbon based fault gases.

True gas concentration change and production as determined by on-line monitoring.

For the purpose of presenting the true gas concentration change linear regression was applied to the data and the following derivatives are calculated:

C_2H_4 Ethylene:

- 2.98 ppm/day (1088 ppm/year).
- 110,3 ml/day

C_2H_6 Ethane:

- 2.19 ppm/day (799 ppm/year).
- 81 ml/day.

The true fault gas production is thus only 10% of the apparent fault gas production that can be the result when basing the calculations on data taken at times when the gas has changed phase location.

The daily variation is 3.8 % for ethylene and 5.9 % for ethane.

These numbers are so small that they have little influence on the transformer condition assessment when there is no gas production ie gas concentrations are low. The series of data obtained in this measurement does not answer the question to how the migration varies with gas concentration.

True gas concentration rate of change using laboratory methods (Toepler).

For the purpose of comparing the continuous monitoring method to laboratory methods the transformer was sampled a number of times and gave the following results. Note that the calculations in these cases are based on measurements spread over several months as opposed to less than 14 days in the continuous monitoring case.

C_2H_4 Ethylene:

- 0.6 ppm/day (219 ppm/year).
- 22 ml/day

C_2H_6 Ethane:

- 1 ppm/day (365 ppm/year).
- 37 ml/day.

Overall levels of gas concentrations/ monitoring device/ true DGA (Toepler).

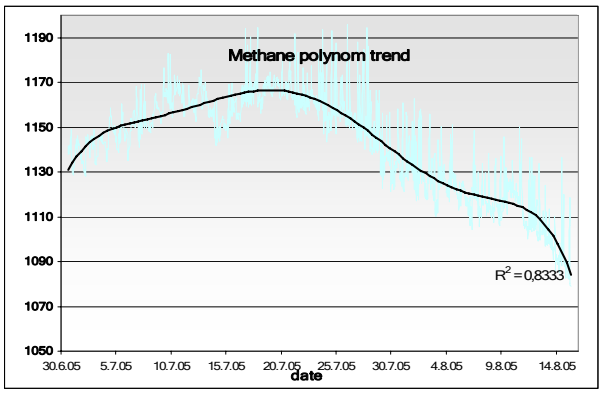
Final readings:	*On-line meas.*	*True DGA*	*Δ %*
Hydrogen	110	*225*	*+ 110*
Oxygen	560	*680*	*Not relevant*
Methane	1080	*1020*	*- 6*
Ethylene	1000	*760*	*-24*
Ethane	540	*455*	*-20*
Acetylene	0	*0.1*	
Carbon monoxide	133	*140*	*+5*
Carbon dioxide	2950	*2240*	*-30*

Oxygen is not considered correct to compare since it is not a gas formed but instead it is consumed,

During sampling, transportation and lab handling it is also possible to contaminate the sample. Nevertheless both methods show an extremely low oxygen levels.

Behaviour of Methane.

Evaluation of methane behaviour during the continuous monitoring is more difficult than the evaluation of other gases.



As can be seen it initially increases but after some time it starts to decrease. These are the data as presented by the monitoring device and they need further penetration to be fully understood.

Due to the fact that Toepler and on-line monitor data are very close it can be assumed that the detected variation is a true variation and only can be interpreted as after the peak at July 20 the rate of methane consumption is higher then the rate of its formation.

Consumption can only be due to chemical reactions like polymerization and oxidation.

As oxygen level was extremely low and the transformer is sealed it can be assumed that was not the reason for the decrease. Instead polymerisation is more likely to be a candidate mechanism.

The behaviour of methane clearly indicates that other reaction types e.g. polymerization then are normally considered for the gaseous hydrocarbon species must be considered in cases where hot core surfaces that may be catalytically active are involved.

Combining two methane will yield ethane and hydrogen which seen to compare well with recorded data.

Summary: apparent gas production rates can be very much higher than true gas production rates. Sampling oil temperature affect data very strongly and most gases show a tendency to migrate between oil and cellulose phases.

For methane, polymerisation may be a cause for concentration variations if catalytically active surfaces are present.

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