Transformer Failure prevented by Gas-in-Oil On-Line Monitoring

The impact of accuracy in evaluating the evolution of a fault

Oil filled power transformers are one of the most important components of electricity generation, transmission and distribution network. The analysis of gases from petroleum products has been performed for decades using gas chromatography. However, this technique was not applied specifically to transformer mineral oil until the late 1960s/early 1970s and is now commonly called dissolved gas-in-oil analysis (DGA). Some of the early developers of the technique were Dr. James Morgan of Morgan Schaffer Systems, Canada, and researchers J.E. Dind, R. Daust and J. Regis from the Canadian utility Hydro-Quebec.

The analysis of dissolved gases, ASTM D3612 - Analysis of Gases Dissolved in Electrical Insulating Oil by Gas Chromatography, has been shown to be one of the most sensitive, as well as easiest to obtain, measures of potential trouble in electrical equipment. Certain gases may be formed due to natural aging but also as a result of faults which may damage the equipment. Some are of immediate concern (such as arcing) while others can have a long term effect (overheating). Periodic analyses of the oil provide a means monitoring the health of this equipment.

The DGA technique involves extracting or stripping the gases from the oil and injecting them into a gas chromatograph (GC). Detection of gas concentrations usually involves the use of a flame ionization detector (FID) and a thermal conductivity detector (TCD).

Removing the gas from the oil is one of the most difficult and critical portions of the procedure. The original method, now ASTM D3612A, required that the oil be subjected to a high vacuum in an elaborate glass-sealed system to remove most of the gas from the oil.

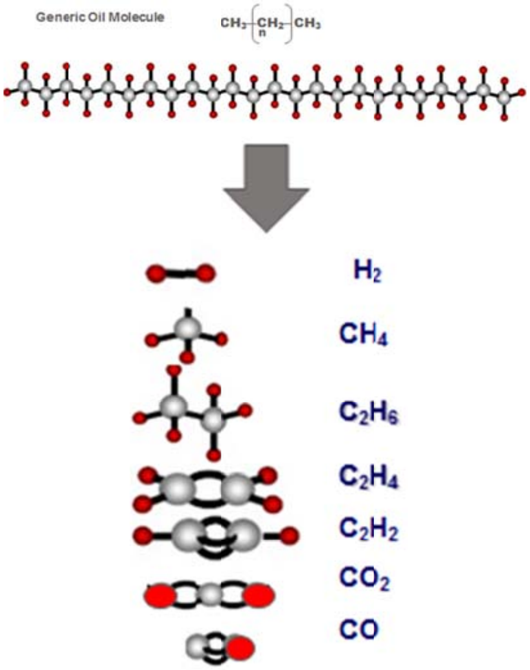
The detection of certain gases generated in an oil-filled transformer in service is frequently the first available indication of a possible malfunction that may eventually lead to failure if not corrected. Arcing, corona discharge, severe overloading, and over-heating in the insulation system are some of the mechanisms that can result in chemical decomposition of the insulating materials and the formation of various combustible and noncombustible gases. Normal operation may also result in the formation of some gases.

In a transformer, generated gases will be found dissolved in the insulating oil. They may also be found in the gas blanket above the oil or in gas-collecting devices. The detection of an incipient fault, if present, involves an evaluation of the amount of generated gas present and the continuing rate of generation. An indication of the source of the gases and the kind of insulation involved can sometimes be gained by determining the composition of the generated gases.

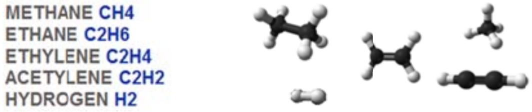
Fault gases are produced by:

- Thermal & electrical stresses;
- Exposure to air;
- Cellulosic insulation starts degrading;
- Contaminant induced chemical reactions.

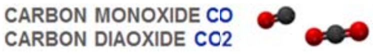
This will cause the chain to break and trigger molecular rearrangement.



Hydrocarbons & Hydrogen:



Carbon oxides:



Atmospheric gases (non fault gases)

Hydrogen is the key fault gas as it is always present in every type of fault.

Three extraction methods are approved: Method A (Vacuum Extraction), Method B (Stripping method) and Method C (Head Space method). They each have their advantages and disadvantages but Method A is by far the longest-standing technique and is still widely used today and offers accurate, reliable sample preparation if followed rigorously.

As required by ASTM (D3612), laboratories must use prepared Gas in Oil Standards of known concentration regularly to validate their extraction efficiency and establish a traceable performance of their process.

The use of control charts as part of a quality assurance program gives any laboratory the ability to show that an analysis is in statistical control. Some of the advantages that can come from bringing a testing process into control are:

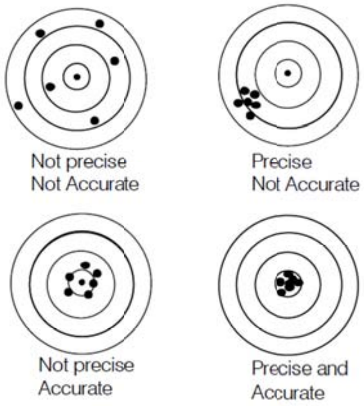
- Ensuring the identification of analytical variations;
- Analysis and examination of the process statistics improves process control during normal operations as well as during process modifications thus allowing for improved method performance;
- Using dissolved gas in oil standards as part of the production flow benchmarks the analytical process and allows for greater confidence in the result;
- A test that shows good statistical control is predictable and can be relied on;
- The chart of a test in statistical control can enables us to determine the experimental error.

DGA Oil Standards are commercially available (*Morgan Schaffer True North DGA Oil Standards*).

When a measurement is made, whether using an ohmmeter, a micrometer, or another laboratory instrument, there is a tendency to accept readings without thinking about their accuracy. Even with the most expensive equipment and under ideal conditions, every measurement is subject to errors and inaccuracies.

The precision of an analytical procedure is a measure of its reproducibility, i.e., the distribution of results about the mean or how close measured values are to each other. Monitoring the precision of analyses on a day to day basis can be difficult. The precision of a method is often a function of the smallest measurable increment, thus the precision may vary. Also, analytical results can often be at or near the detection limits making it difficult or impossible to set control limits. Accuracy is a qualitative term and refers to the agreement of a measured value to the true, accepted, or known (correct) value. One approach used to estimate the accuracy of a method is the analysis of known materials.

Refer to Figure 1



M. Cyr, Morgan Schaffer, 2007

Examples of Precision and Accuracy
FIGURE 1

The objective of a quality assurance program for laboratory testing is to reduce errors in measurements to allowable levels and to provide a means of confirming that the measurements made have a high probability of being as accurate as is necessary. Quality assurance is comprised of two separate but related activities:

- Quality control, which is the application of procedures in a repetitive and consistent fashion for controlling the measurement process and its quality so it satisfies the recipient's needs, and
- Quality assessment, the process that confirms the testing system is operating within acceptable limits and that the task of quality control is being performed effectively. This needs to be an on-going operation.

Not only does quality assurance cover all laboratory operations but also sample collection and identification, training and other areas as well.
Remember, DGA is a three step process and each step has to be performed in compliance with a

rigorous procedure to ensure reliable results.

1. Oil sampling
2. Gas extraction (ASTM D3612)
3. Gas Measurement (GC)

Oil sample identification is essential in order to take full advantage of this process to update the database and enable further analysis.
Required information:

- Date & Time
- Temperature
- Pressure
- Serial Number
- Equipment ID
- Apparatus type
- Location
- Description
- Manufacturer
- Rated kV
- MVA
- Year manufactured
- Fluid volume
- Fluid type
- Owner

DGA is an integral part of Condition Based Maintenance programs. To be successful, it must be adapted to your needs and common mistakes avoided:

- Analysis intervals are too infrequent
- Poor sampling techniques
- Delay in getting samples to the laboratory
- Delays in getting the results back
- Poor information submitted to the lab (incomplete)
- Lack of correct tests
- Poor interpretation of the tests
- Failure to integrate with other condition based technologies.

Transformers are all different and every unit has a distinct signature. When a unit is first energized, it's important to take an oil sample and perform a DGA to establish a baseline for this unit. Thereafter, DGA's are performed annually or more frequently depending on the criticality and/or the detection of an incipient fault. Historical DGA results should be accessible to calculate trends.

Various DGA results interpretation methods are used for condition assessment. The most popular ones are:

- IEC 60599 Ratios
- IEEE C57.104, Limits, rates and TDCG
- Rogers Ratios
- Key Gas Method
- Duval Triangle
- Trend Analysis
- "NEW GUIDELINES FOR INTERPRETATION OF DGA" CIGRE Task force 15.01.01,Octr 1999
- Companies guidelines
- More…

Diagnostic reliability is affected by the accuracy of the DGA measurement results as demonstrated by a study conducted by CIGRE and covered in an article published by Dr. Michel Duval and Dr. Jim Dukarm.. (IEEE August 2005, M. Duval, J. Dukarm, Improving the reliability of transformer in gas-in-oil diagnosis)

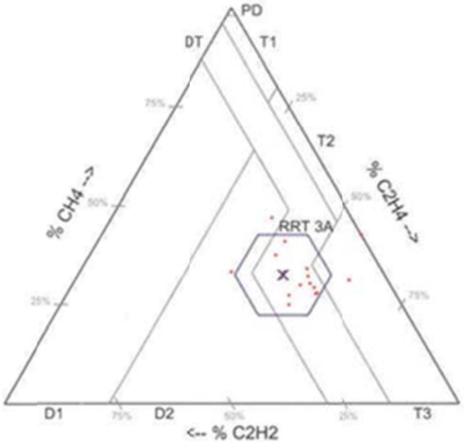


Figure 3. CIGRE results for RRT at low concentration levels. Results of individual laboratories (•) and prepared values (x) are given.

Regardless of the method used, precise and accurate DGA results are crucial to your decision making process.

Precision and accuracy is also imperative to enable trending calculation for early warning of all types of developing faults. Wrong DGA results will lead to wrong diagnostic and ultimately to wrong decision.

Counting only on periodic DGA is often not sufficient to prevent catastrophic failures and the fault condition can change very quickly.

Fortunately, the evolution of technology has enabled utilities to install on-line monitors (Key fault gas or multigas) for all critical transformers. Furthermore, utilities now have the possibility to perform a lab precision DGA in the field when the situation is critical.

When on-line monitoring is used, the sampling procedure must be adapted to enable validation of the readings periodically. In addition to the sample information sent to the laboratory, take note of the readings so that the lab results can be compared to the monitor readings, at least annually.

- Date & Time
- Monitor model no.
- Serial number
- Transformer ID
- Location
- Recorded readings (all)
- Date
- Download database file (recorded readings and event log)
- Review alarm settings

Note: When the on-line monitor has a sampling valve, the oil sample should always be taken from that valve for comparison.

Conclusion

DGA is the most important oil test for insulating fluid in electrical apparatus as it provides a wealth of diagnostic information to detect incipient faults. As such, it has become a standard in the utility industry throughout the world.

Whether DGA results are obtained from a laboratory, portable DGA analyzer or on-line monitor, there must be no room for misleading conclusions.

Laboratories must be able to demonstrate at all-time their effectiveness in providing precise and accurate results. Variances and inconsistencies in the results will lead to a wrong diagnostic, corrupt the DGA database and invalidate trending calculations. As DGA can also be performed in the field using portable gas chromatographs, it is also highly important to calibrate these instruments regularly to ensure their precision and accuracy, and thus maintain results' trustworthiness.

In both cases, the regular use of DGA Oil Standards is imperative as it will validate the integrity of the DGA process and detect any deviation from the precision and accuracy objectives.

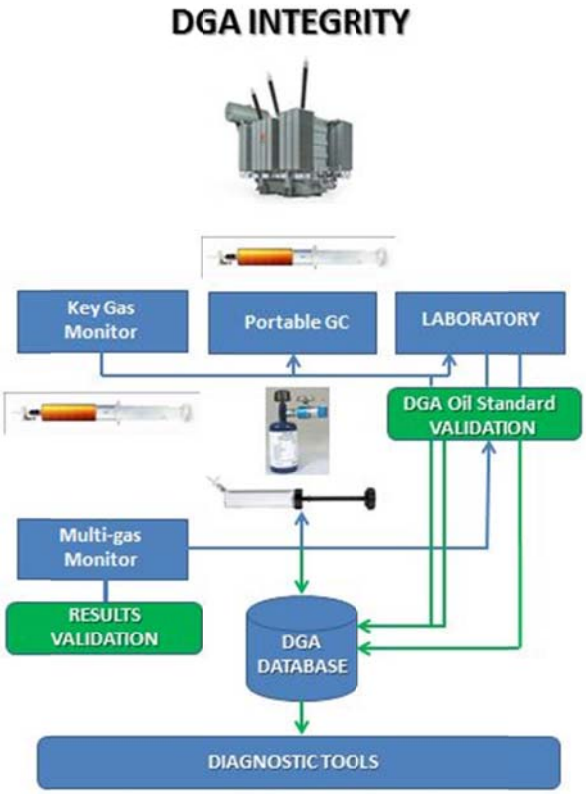
However, periodic oil sampling and DGA performed by a laboratory or a portable fault gas analyzer will rarely enable early fault detection. On-line monitoring is the only method that will provide continuous information to detect and monitor incipient faults.

As with laboratories and portable analyzers, data from on-line monitors must be validated regularly. It is therefore highly recommended to include the on-line monitor current reading every time an oil sample is collected from the transformer. The oil sample should always be taken from the instrument sampling port as this is the best point for having access to oil representative of the transformer condition.

When an alarm is triggered by a key gas on-line monitor, an oil sample must be collected to enable a diagnosis, as the values of all fault gases are required to draw any conclusion and make the proper decision.

With on-line multi-gas analyzers (On-Line DGA Monitors), the current practice is also to take an oil sample to validate the instrument readings using a portable or laboratory DGA. This is somewhat puzzling as the purpose of a DGA monitor is to provide DGA results that can be used to diagnose and monitor the evolution of a fault.

One must therefore conclude that confidence in on-line DGA results will only be possible if stringent DGA accuracy verification processes are implemented. Only if laboratories, portable GCs and on-line monitors continuously maintain their precision and accuracy, will utilities be able to take full advantage of DGA results, independently of their source.



References

1- Technical bulletin MS-25 – Dr James E. Morgan. A guide to the interpretation of transformer fault data;
2- Improving the assessment of transformer condition by enhancing laboratory accuracy using dissolved gas in oil standards. – Peter Lazarski, National Grid – Marc Cyr, Morgan Schaffer (2008 Doble Engineering Company - 75th Annual International Doble Client Conference
3- ANSI/I EEE C57.104-1978 - American National Standard guide) for the detection and determination of generated gases in oil-immersed transformers and their relation to the serviceability of the equipment;
4- Using Dissolved Gas Analysis to Detect Active Faults in Oil-Insulated Electrical Equipment - Lance R. Lewand – Doble Engineering
5- IEEE August 2005, M. Duval, J. Dukarm, Improving the reliability of transformer in gas-in-oil diagnosis.

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Claude Hermann
Sales Director – Eastern USA and Mexico
Morgan Schaffer Inc.