Online Transformer Gas Diagnostics on the Basis of IEC 60567/60599

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1. Introduction

The laboratory methods of dissolved gas analysis (DGA) are summarized in IEC 60567. Eleven individual gases can be determined. An accuracy of ± 15 % is possible on the basis of external standards which combines extraction and gas chromatographic analysis. Sampling influences are not known and remain an unsolved problem. Online techniques for DGA are developed with a view to measuring continuously and without sampling errors. In practice, this meant a transfer of laboratory devices to online conditions. Some modifications are known for gas extraction with membranes and for analysis with IR spectrometers and photo-acoustic detection.

IEC 60599 describes transformer diagnostics on the basis of DGA. The study of several years of statistics of gas chromatographic laboratory analyses with 5 (H_2, CH_4, C_2H_2, C_2H_4, C_2H_6) or 7 (additionally C_3H_6, C_3H_8) fault gases has led to value ranges for three quotients dependent on types of fault. The practical application with the help of DGA interpretation tables for the determination of the six types of fault is supported by diagrams showing these quotients. What is visually more interesting is the Duval triangle [1] which is also listed and uses a diagram of the fault gases CH_4, C_2H_2 and C_2H_4 that is transformed to 100%, thus using the different energy densities of formation for diagnostics. The triangle can be used directly in its visual form and shows that diagnostics is also possible with three fault gases only. In practice, this can lead to diagnostic problems, e.g. in case of partial discharge and of leakages in OLTC vessels. The reason is that hydrogen in not included.

In unplanned situations of a gas alarm of the Buchholz relay, IEC 60599 cannot really help. The described way has no physical basis.

The aim of this paper is to demonstrate the following solutions:
- comprehensive quality criterion
- visualisation area for the complete fault gas part in transformer gases dissolved as well as undissolved.

2. Alternative to the laboratory-based way

The laboratory-based way means to make a complete individual gas analysis. This is necessary for the calculation of the solution pressure. The fault gas concentrations are used to calculate the quotients for diagnostics.

2.1 Online monitoring

The basis of the gas extraction of the known laboratory methods is the determination of the dissolved gas as volume (total gas content). Alternatively, it is possible to measure the pressure of the dissolved gas (solution pressure) on the basis of the Henry and Dalton's Law.

The solution pressure can indeed be measured directly, continuously and with minor deviations using the new technique of the online equilibrium gas (Transformer Gas Monitor TGM by GATRON GmbH). The general sampling requirements (oil circulation, hermetic conditions) are met. In practice, it has been possible to prove the nitrogen saturation of the vessel oil in air-breathing transformers with the help of the TGM. Deviations may be due to technological reasons (degassing/resaturation, extreme oxygen consumption).

The measured solution pressure offers two advantages:
- It is not necessary to make a full gas analysis online for calculation only.
- It is possible to develop a comprehensive quality criterion for DGA.

The comprehensive quality criterion can be developed from the online equilibrium gas because it offers alternatives to sampling and extraction with the help of the known analytic techniques. Consequently, the techniques for DGA (manual or online) can be differentiated on the basis of periodical or continuous sampling as well as in terms of the three extraction techniques (Fig. 1).

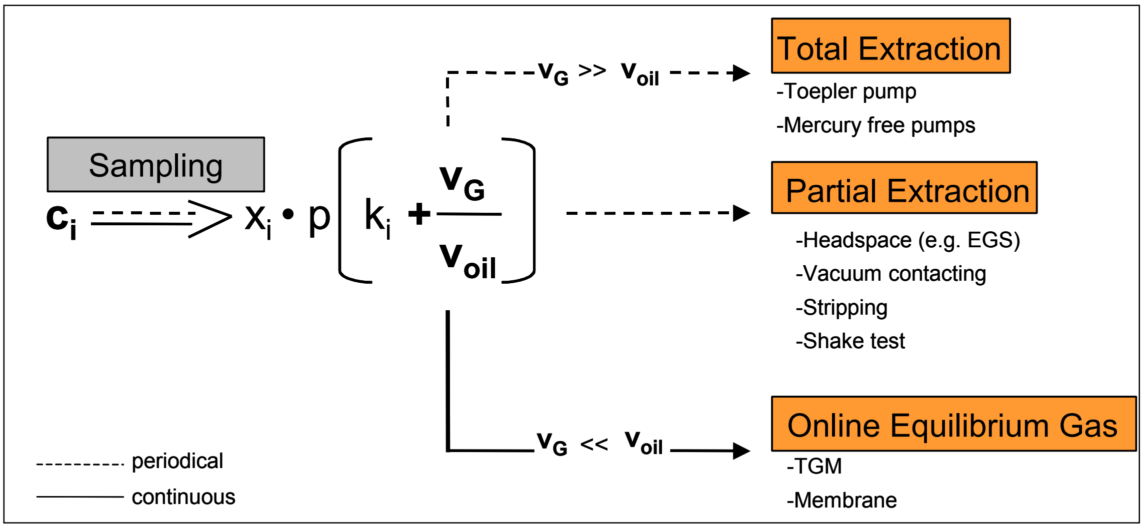

Fig. 1: Sampling and extraction techniques for DGA

The fundamental problem of DGA becomes evident because of potentially fault-prone sampling between the gas concentrations in the original oil (c_i) and the concentrations in the extracted equilibrium gas (x_i). The gas extraction can be described by the gas pressure (p) and the solubility coefficient (k_i).

The differentiating characteristic between the three extraction techniques is the ratio between the gas volume (v_G) and the oil volume (v_{oil}). This may be set using different technical means. The extracted gases are analyzed in a calibrated manner, mainly by means of gas chromatography.

For quality control, the following natural internal standard (NIS) may be formulated:

Full analyses with different sampling and extraction techniques only show completely identical results if these are simultaneously identical with the actual values in the original oil, too.

Accuracy limits for full analyses (without sampling):
nitrogen, oxygen, solution pressure ±8% (measured solution pressure ±1%)
fault gases ±15% (analogous to IEC 60567)

The diagnostic suitability of results of DGA can be proved by comparing a technique of total or partial extraction with a technique of the online equilibrium gas. The monitoring needs to be within the double accuracy limits for full analyses. For this, a minimum of two such techniques which are free of sampling influences must be found. The successful search is shown in the extensive descriptions of the TGM and EGS (Extraction Gas Sampler by GATRON GmbH) procedures [2]. This means that NIS application has started. The brand name for this is: **N_2IS based !** ®

2.2 Online diagnostics

A new, powerful tool for diagnostics has been developed. It is based on the assignment of the gases to the main fault types:

H_2	–	partial discharge
C_2H_2	–	electrical discharge
CH_4+	–	thermal fault

Here CH_4+ is the newly introduced parameter "monitoring sum of hydrocarbons". It is the weighted sum of the hydrocarbons CH_4, C_2H_6, C_3H_8, C_2H_4 and C_3H_6.This sum can be measured directly with a sensor or calculated from a full analysis. Using the three dominant fault gases of the main fault types allows the fault gas triangle (FGT) shown in Fig. 2 to be created.

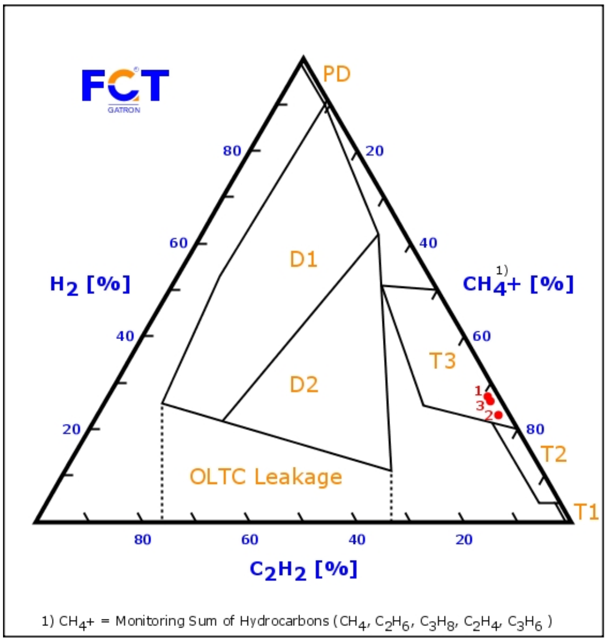

Fig. 2
Fault Gas Triangle for diagnostics according to IEC 60599
•diagnostic point of the operating example

The result is a closed diagram which includes all fault gases. For the practical application of the gas triangle, it makes no difference whether the monitoring sum is measured with a sensor or calculated with the help of laboratory analyses. The concentrations of CH_4+, H_2 and C_2H_2 are transformed to 100% and then the registration in the fault gas triangle made. The conditions of use are the ones laid down in the standard: typical concentration values of the fault gases, additionally online CH_4+ > 200 ppm and the gas production rates known. For diagnoses it is necessary to visualise the fault types. This can be done using the diagnostic schemes (IEC 60599, MSS, Rogers, etc.) known. The marked areas in the fault gas triangle in Fig. 2 were calculated for the six fault types from the value ranges of IEC 60599.

3. Practical application

The typical application of the fault gas triangle can be demonstrated by a practical example. The operating diagram of a suspect industrial transformer is shown in Fig. 3. The TGM-D (diagnostic variant of TGM) contains a sensor block which can measure the CH_4+ content directly. Additionally, an external laboratory analysis of the first fault period (EGS) on 09.07.2008 is shown in the diagram. On 02.09.2008, the second fault period begins, first seen in the operating diagram through the presence of CH_4+ and then later of H_2. The measured results are displayed in the fault gas triangle: TGM-D of 09.07.2008 • 1, EGS of 09.07.2008 • 2, TGM-D of 20.09.2008 • 3.

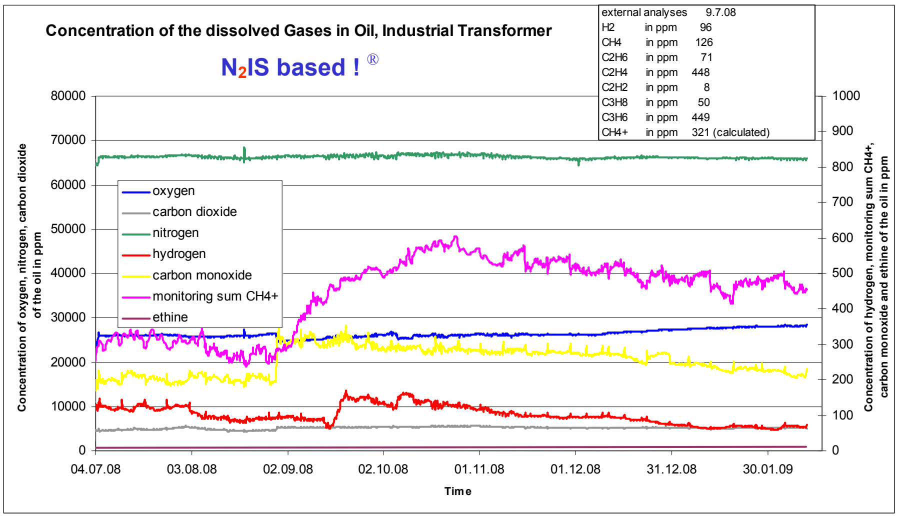

Fig. 3 Operating diagram for the online diagnostics (TGM-D)

Fig. 2 shows that all three diagnostic points are in area T3. The EGS analysis of 09.07.2008 on basis of IEC 60599 with the evaluating procedure known leads to the same result T3.

The fault gas triangle offers the following advantages for diagnostic purposes:
- reduced number of sensors for online gas monitoring with visualised diagnostics (TGM-D),
- visualised presentation of laboratory analyses of suspect transformers.

The discussion about the influences which analytical mistakes, the open type of transformers or accumulated faults as well as the tightness of the OLTC vessel becomes easier.

For free gases of the Buchholz relay, it is necessary to use a modified procedure: First they are tested in terms of the equilibrium criterion, then they are corrected to the original composition on the fault location and finally the CH_4+ content is calculated from them. Then it is possible to use the fault gas triangle in the same way as for dissolved gases.

On the basis of the equilibrium gas in the TGM-D it is optimal to measure the equilibrium criterion directly as the difference to the Buchholz gas with the result “fault gas or air”. In the case of “fault gas”, an stored sample of the Buchholz gas, which is kept separately from the oil, can be taken for a full external gas analysis.

Fig. 4 shows how concrete fault gas quotients can be changed on the way through the oil from the fault location to the Buchholz relay [3]. The separation step number n is defined as a function of gas exchange, which is quantified depending on the oxygen/nitrogen relation dissolved in the oil and free in the Buchholz gas.

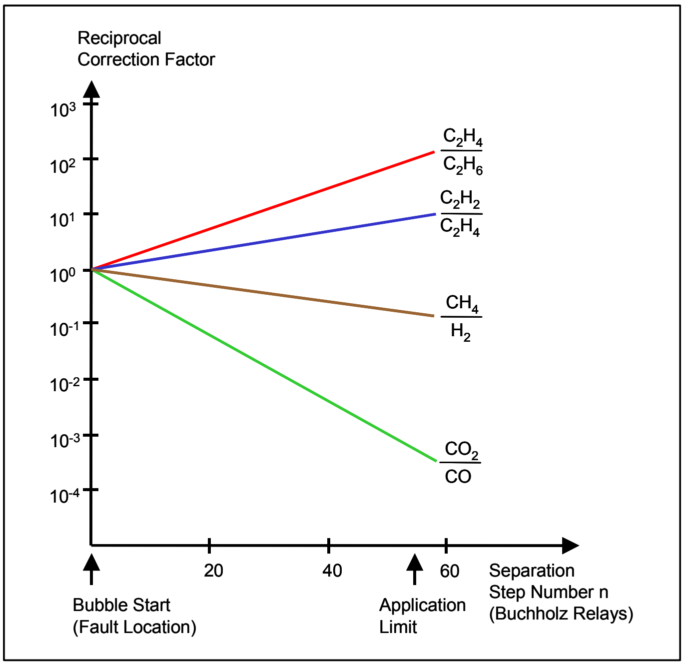

Fig. 4
Reciprocal correction factors for the fault gas quotients of IEC 60599 for transferring the Buchholz gas into the original fault gas (fault location)

The application of the fault gas triangle will lead to statistics of fault types which are independent of the diagnostic schemes known. This will open up new possibilities for better diagnostic performance.

4. Summary

Several years of statistics of gas chromatographic laboratory analyses allows the number of individual fault gases to be reduced for visualisation. The result is a fault gas triangle (FGT) with the coordinates hydrogen, acetylene and the monitoring sum of hydrocarbons, which includes the rest of the fault gases.

In connection with the online equilibrium gas, different problems of DGA have been solved. Here are the results:

- NIS criterion for analytical quality,
- visualisation of laboratory and online data for diagnostics,
- online monitoring without full analytical devices,
- complete implementation of Buchholz gases.

This increases the acceptability of DGA as the leading method for transformer diagnostics.

Literature

[1] Duval, et al., CIGRE Symposium Berlin 1993, Paper 110-14
[2] Comparison of the Accuracy of Real Gas Analyses in Oil (TGM/EGS) GATRON Paper, Greifswald 2008
[3] Bräsel, E.; Brunner, E.; Hartmann, E. Neue Hilfsmittel zur Diagnoseeignung von Gasen aus dem Buchholz-Relais Elektrizitätswirtschaft H25, pp. 16-24, (1999)