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Application of Dissolved Gas Analysis Standards and Methods on Raw Gas Sample

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Abstract: *Dissolved gas analysis (DGA) is a tool to diagnose and identify faults that causing abnormal thermal or electrical activity inside power transformers, which could give rise to the aging and degrading of oil and pressboard. Different DGA standards and methods will be reviewed, and discussed in the paper, followed by a demonstration of application of three DGA method on a dissolved gas dataset.*

Keywords: *Dissolved gas analysis, DGA, Power transformer, Insulation*

1. Introduction

Insulation, which consists of oil and cellulose, is an important component in power transformers. It serves as dielectric, coolant, and provides support to windings. Faults that causing abnormal thermal or electrical activity inside transformers could give rise to the aging and degrading of oil and pressboard. In the process of transformer operation, the chemical reaction of overheating and electrical activity will cause the gases to be dissolved in the transformer oil. These gases can help the operator to detect the fault in the early stage and avoid later unplanned loss [1].

Although dissolved gas in oil-filled transformers is complex, Dissolved gas analysis (DGA) is a tool to diagnose and identify the fault. In this paper, some DGA standards and methods will be reviewed, followed by results demonstration of three DGA method on a dissolved gas dataset. In addition, the DGA results are analysis and discussed.

2. Review of DGA Analysis Standards and Methods

In this section, two internationally accepted standards, IEEE Std C57.104™-2008 and IEC 60599:2015 (BS EN 60599-2016), and two analysis methods, Duval Triangle and Duval Pentagons, will be briefly reviewed, explained, and discussed.

2.1. IEEE Std C57.104™-2008 Standard

The IEEE C57.104 gives detailed procedures on interpreting gases generated in mineral-oil-immersed transformers. It suggests that, during the operation of oil-filled transformer, any abnormal quantities of gas generated should be detected at the earliest stage to avoid or minimize damage and failure. The methods that can be used to detect gas is direct measuring in the gas space, relay, and oil. And after gas samples are collected, separated components in an extracted gas sample could be analyzed.

There is a four-level criterion that can be used to evaluate whether the transformer condition and behavior are normal. If conditions 2, 3, 4 exits, and the fault in transformer that causes that generated gas is still active, the fault type shall be investigated [2]. Once an abnormality is detected, it shall be evaluated based on the guidelines and recommended actions such as supplementary analysis shall be taken. Methods to determine the possible type of fault are kay gas method, Doernenburg ratio method and Rogers ratio method.

Key gases are generated gas that are typical or predominant at various temperatures, including Carbon Monoxide (CO), Hydrogen (H2), Methane (CH4), Ethane (C2H6), Ethylene (C2H4), and Acetylene (C2H2). Key gases are formed due to oil and paper insulation degradation [1]. They can be used to qualitatively evaluate whether the fault types are overheated oil, overheated cellulose, partial discharge in oil, or arcing in oil.

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Doernenburg ratio method and Rogers ratio method use gas ratios to determine whether a possible fault occurs. The five ratios used, as listed below, are based on the thermal degradation principles including decomposition of cellulosic insulation and decomposition of oil. The ratios are:

Ratio 1 (R1) = CH4/H2

Ratio 2 (R2) = C2H2/C2H4

Ratio 3 (R3) = C2H2/CH4

Ratio 4 (R4) = C2H6/C2H2

Ratio 5 (R5) = C2H4/C2H6

Then the ratios could be used to diagnose the fault type, when the Doernenburg ratio method utilizes R1, R2, R3 and R4, and the Rogers ratio method utilizes R1, R2 and R5. However, in some cases, the Rogers ratio method is not able to give any conclusion [1].

When the investigation is completed, operator shall make adjustments on sampling interval and operation procedures based on the data and investigation results.

2.2. IEC 60599:2015 (BS EN 60599-2016) Standard

The IEC 60599:2015 (BS EN 60599-2016) is a British standard that provides guidance on interpreting and analyzing the concentration of dissolved and free gases to detect and evaluate faults. This standard is scoped to mineral oil-filled electrical equipment with cellulosic paper or pressboard-based solid insulation.

The BS EN 60599 uses ratio method to determine whether one of the six faults occurs. The ratios are C_2H_2/C_2H_4, CH_4/H_2 and C_2H_4/C_2H_6. Each of the six faults has its own pattern of hydrocarbon gas composition. It's the reason why it can be interpreted with the gas ratio.

The ratio method has some limitations. First, there are some case that cannot be concluded to any of fix faults if the ratio is out of range for all cases, which is called missing code. Second, fault D1 and D2 are overlapped, resulting some cases have dual attribution of faults. However, different adjustments and actions shall be made since D1 and D2 have different discharge energy.

In addition to the basic ratios, there are some other ratios, such as CO_2/CO, that could be used to determine possible fault. For example. If CO_2/CO ratio is greater than 10, there might be mild overheating of paper or oil oxidation.

2.3. Duval Triangle 1 Method

The Duval Triangle 1 is a diagnostic method involving three hydrocarbon gases, Methane (CH_4), Ethylene (C_2H_4), and Acetylene (C_2H_2), that are generated because of increasing level of energy [1]. There are six individual zones of discharge and thermal fault, and a DT zone as mixtures of electrical and thermal faults [2]. Concentrations of CH_4, C_2H_4, and C_2H_2 are used to locate a point inside one zone of the triangle. The Duval Triangle 1 legend is shown in table 1.

Table 1: Duval Triangle Legend

PD	Partial Discharge
D1	Discharges of low energy (sparking)
D2	Discharges of high energy (arcing)
T1	Thermal faults of temperature <300 ℃
T2	Thermal faults of temperature 300 ℃<T<700 ℃
T3	Thermal faults of temperature > 700 ℃
DT	Mix of thermal and electrical fault

Idea of the Duval Triangle 1 is barycentric coordinates, which uses three non-negative number (a_0, a_1, a_2) which satisfies $a_0 + a_1 + a_2 = 1$ to locate a unique point inside the triangle or on the triangle edge [6]. The triplet of numbers corresponds to the percentages of CH_4, C_2H_4, and C_2H_2 in the three gases. Study has shown that the Duval Triangle is more effective than Doernenburg and Rogers ratio methods [6].

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2.4. The Duval Pentagon 1 and 2

Duval Pentagon 1 is a diagnostic pentagon involving Hydrogen (H2), Methane (CH4), Ethane (C2H6), Ethylene (C2H4), and Acetylene (C2H2). There are seven fault zones within Duval pentagon 1, six basic IEC and IEEE fault types (PD, D1, D2, T1, T2, T3) and one additional sub-type S (stray gassing of mineral oil). Similar to Duval pentagon 1, Duval Pentagon 2 is a diagnostic method involving the same gases but covering more sub-type faults [3]. As shown in table 2.

Table 2: Duval Pentagon Legend (sub-type faults)

T3-H	Thermal faults T3-H in oil only
C	Thermal faults T3-C, T2-C, and T1-C with carbonization of paper
O	Overheating T1-O <250 ℃
S	Stray gassing S of mineral oil at 120 and 200 ℃ in the laboratory

The gas sample could be converted into the Cartesian coordinate system to form an irregular polygon. Then the centroid of this polygon would locate in one of the fault zones, and the possible fault type or subtype is discovered [4].

There is a problem of using Duval Pentagons. Since pentagon vertexes are not affinely independent in a plane, the mapping of gas proportions to a point inside the pentagon is many-to-one. This would result in that the same point is located even if the gas proportions used are very different, and lead to a misdiagnosis. Although the many-to-one mapping problem may rise double on whether Duval Pentagons method is accurate, the pentagons have been performing well up to now. Therefore, even if the many-to-one mapping problem exists, Duval Pentagons is used to bring complementary information [5].

3. Dataset DGA Analysis Results

This section includes DGA analysis results on dataset 8612.xlsx. Methods used are ratio method introduces in IEC 60599:2015 (BS EN 60599-2016), Duval Triangle mapping method, and Duval Pentagons mapping method.

Assumptions made during analysis:

- NS values (non-significant whatever the value) are numbers less than and equal to 0.001.
- The value range includes two boundaries (0.1-0.5 are values satisfy 0.1 <= x <= 0.5).
- Transform for all cases are identical, including age, station, power, etc.+
- Gas data are collected using same method, and under same circumstances.

Since the laboratory result on the DGA samples are not provided, assume the results of Duval Pentagons are all correct during comparison between methods.

Table 3: DGA Results

Case	IEC Ratio Method	Duval Triangle	Duval Pentagon 1	Duval Pentagon 2
1	NA*	DT	D1	D1
2	NA*	D1	D1	D1
3	NA*	D1	D1	D1
4	NA*	T1	D1	D1
5	NA*	D1	D1	D1
6	NA*	DT	D2	D2
7	NA*	D1	D1	D1
8	NA*	D2	D1	D1
9	NA*	PD	D1	D1
10	NA*	DT	S	S

NA* refers no classification of IEEE/IEC due to missing code

As shown in the table 3, the IEC Ratio Method is not applicable for all ten cases provided in the dataset. The reason is that the gas samples are not within any ranges in the DGA Interpretation Table. This method is only usable when the DGA sample ratios are in a specific range, otherwise the method would lead to missing code result and the fault type would be able to be identified. Therefore, the IEC Ratio Method could be used to identify the possible fault type instead of detecting a fault [6].

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Duval Triangle 1 Method can identify thermal or discharge fault effectively. However, studies have shown that Duval Triangle 1 is not as effective as the Duval Pentagon on diagnosing partial discharge event, which generates hydrogen [4]. Besides, there is another limitation of Duval Triangle 1. It does not include a zone that represents normal condition. Thus, gas dissolved in the transformer due to normal insulation aging would be detected as fault, which leads to analysis error [7].

As shown in case 10, Duval Pentagons solve the above diagnoses error problem by including zone “S” that representing stray gas that generated during normal aging process of transformer insulation system. However, different DGA results of Duval Triangle and Pentagons may indicates that the transformer has a combination of faults. Thus, Duval Pentagons shall not replace Duval Triangle but to provide additional information [7].

An advantage of Duval Pentagon 2 is that it can assess subtype faults. A major factor in making decision to avoid catastrophic damage when a thermal fault occurs in the transformer is to know the degree of involvement of paper carbonization. Although this situation is not included in the ten cases, when the DGA sample locates in the “C” zone of Duval Pentagon 2, it reveals a certain paper carbonization [7].

4. Conclusions

Regular monitor and assessment on transformer condition are important to avoid further failures inside transformers. Ratio methods such as Doernenburg, Rogers, and IEC Ratios are only applicable when the ratios of dissolved gas are in range, otherwise the result would be missing code and the possible fault type is not diagnosed. Therefore, ratios-based methods could only be used to identify faults instead of detecting them.

Compared to ratios-based methods, Duval Triangles and Pentagons covers a wider range of gas samples. Besides, Duval Pentagon 2 is also able to identify four subtypes of thermal faults in addition to the six basic faults. This could help to make appropriate adjustment to the transformer.

Since the laboratory result on the DGA samples are not provided, the accuracy of the DGA result is not calculated. But there are other ways to improve the DGA performance such as using machine learning techniques or supplementary tools like Duval Triangle 2.

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