3D Implementation of Rogers Method for Power Transformer Oil Condition Monitoring

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Abstract

Power transformers insulating oil condition monitoring and assessment have been important components of assets management plan for power utilities. Dissolved gas analysis methods have been valuable tools for detecting incipient faults in oil-filled power transformers. The advances in sensors and computers technologies coupled with the versatility of the latter have opened doors to on-line monitoring of oil-filled power transformers and auxiliary equipment. In this paper, 3D graphical representation the Rogers method is implemented so as to be included to power utilities on-line monitoring system toolbox. JAVA language and JAVA Binding for OpenGL (JOGL) are used for development purpose.

Key words: Power Transformers, DGA, Rogers Method, Computer Graphics, 3D, Oil Condition Monitoring

1 Introduction

Power transformers are the most critical node in a power system. Even though these devices of about 40 years of life expectancy are not failure-prone, unexpected disruptions do occur which might result in outages of the power system. Outages are costly to power utilities and detrimental to their image in front of their customers [1]. The Council on Large Electric System (CIGRE) conducted a research to determine the main causes of power transformers failures, results of which are illustrated in Figure 1 [2] . Another survey with the similar objective has been directed from 1975 to 1998 by Hartford Steam Boiler (HSB). The results of the survey are summarized in Table 1. Even though the parameters considered by these two studies were not all the same, both agreed on the fact that deterioration on insulating media is one of the main causes of power transformers

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breakdown. Mineral oil, in addition to cellulose, has been used as insulating in power transformers for their insulating and cooling functionality. However, this oil, while generating amounts of gases which dissolve in it, steadily deteriorates due abnormal electrical and mechanical to which power transformers are subject. The natures and quantities of generated gases are indicative of fault types in the transformers. Dissolved Gas in oil analysis (DGA) has proven to be a valuable tool to power utilities for detecting incipient faults in power transformers. Manifold of standards-compliant DGA methods, among which the Roger ratio method have been developed over the years. In this paper:

- We will review the general principle of DGA methods and the Roger Ratio method's tenets will be examined (Section 2).

- Specifications for a three dimensional representation of the Roger Ratio method is provided in (Section 3).

- An implementation in the JAVA programming language is given in (Section 4).

Table 1 Root causes of power transformers failure as reported by HSB [3]

	1975	**1983**	**1998**
Lightning surges	32.3%	30.2%	12.4%
Line surges /External short circuit	13.6%	18.6%	21.5%
Poor Workmanship/Manufacturer	10.3%	7.2%	2.9%
Deterioration of Insulation	10.4%	8.7%	13%
Overloading	7.7%	3.2%	2.4%
Moisture	7.2%	6.9%	6.3%
Inadequate Maintenance	6.6%	13.1%	11.3%
Sabotage and Malicious Mischief	2.6%	1.7%	0%
Loose Connections	2.1%	2.0%	6%
All others	6.9%	8.4%	24.2%

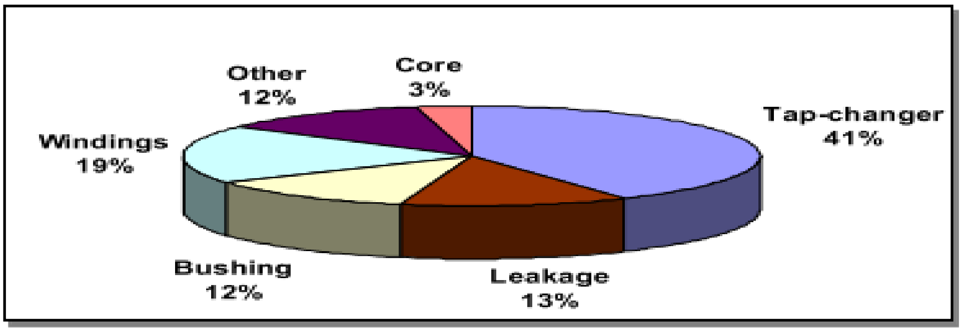

Figure 1 Causes of power transformers failure – CIGRE SURVEY[2]

2 Dissolved gas analysis

In the 1970s, DGA was adopted as a predictive maintenance tool in result of extensive researches done by organizations such as Westinghouse Electric Corporation, Analytical Associates, Inc.[4] . The general principle that lays the foundations for DGA is described in [4]–[6] as follow: oil-insulated transformers during their operations are exposed to thermal, electrical, and mechanical stresses. Molecules of the insulating oil which is a complex mixture of aromatic, naphthenic and paraffinic hydrocarbon, will break down into particles at the end of these stresses. These particles undergo a series of chemical reactions to bring out new components among which are different type of gases. This whole process is referred to as the cracking process. Depending on where the stresses took place, their severity and their type, the natures and quantities of formed gases will vary. When transformers insulating oil molecules experience cracking, gases formed –which are for the most part hydrogen (H_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_2), propane (C_3H_8), propylene (C_3H_6), butane (C_4H_{10}) and butyl ($-C_4H_9$) – will quickly dissolve in the insulating oil in different concentrations. By sampling the transformer oil and performing a qualitative and a quantitative analysis of dissolved gas in oil using gas chromatography, it is possible to determine the kind of fault transformers might have undergone, thus allowing appropriate measures to be taken for transformers maintenance, reconditioning or replacement.

Over the years several DGA methods among which the Rogers ratio have emerged. Rogers ratio methods use five key gases dissolved in oil namely H_2, CH_4, C_2H_6, C_2H_4 and C_2H_2, to compute 4 ratios, namely CH_4/H_2, C_2H_6/CH_4, C_2H_4/C_2H_6, C_2H_2/C_2H_4 that correspond to codes whose combinations help in diagnosing the types of faults at the origin of the gases formation [4]. The diagnoses of these faults are results of years of empirical observations. A three-ratio version of the Rogers ratio referred to as the IEC ratio method exists, where C_2H_6/CH_4 is not used since it merely represents a limited temperature range of decomposition [7]. However, the four-ratio method is likely to generate combinations of codes that will not match a known fault. Unlike its counterpart, the third-ratio method is more accurate in determining the kinds of faults that causes the gases generation. The codes generated by the three-ratio method **Table 2**, and the interpretations given by the combinations of the generated codes **Table 3** are given below. A 3D implementation of the Rogers ratio's three-ratio will be the topic of the next section.

Table 2 Rogers ratios codes [7]

Ratio range	Ratios		
	$\frac{C_2H_2}{C_2H_4}$	$\frac{CH_4}{H_2}$	$\frac{C_2H_4}{C_2H_6}$
$\leq \mathbf{0.1}$	0	1	0
0.1 – 1	1	0	0
1.0 – 3.0	1	2	1
$\geq \mathbf{3}$	2	2	2

Table 3 Rogers ratios faults types [7]

$\frac{C_2H_2}{C_2H_4}$	$\frac{CH_4}{H_2}$	$\frac{C_2H_4}{C_2H_6}$	**Diagnosis**	**case**
0	0	0	No fault	**-**
0	1	0	Partial discharge of low energy	**PD**
1	1	0	Partial discharge of high energy	
1,2	0	1,2	Discharge of low energy, arcing	**D1**
1	0	2	Discharge of high energy, arcing	**D2**
0	0	1	Thermal fault 150°C, conductor overheating	**T1**
0	2	0	Thermal fault 150°C–300°C, mild oil overheating	
0	2	1	Thermal fault 300°C–700°C, moderate oil overheating	**T2**
0	2	2	Thermal fault 700°C, severe oil overheating	**T3**

3 Specifications for a 3D representation of the Rogers ratio method

The system to be developed will use CH_4/H_2, C_2H_2/C_2H_4 and C_2H_4/C_2H_6 ratios to locate in a 3 dimensional space the type of electrical, thermal stress experienced by a transformer at a given period. Three steps are required to achieve this:

- Defining the axes and the scales of each the axes of the 3 dimensional space,
- Representing regions of the 3D space that correspond to each type of known faults,
- Locating faults experienced by the transformer according to the ratios' current values.

3.1 Definition of the axes and axes' scales

The x, y and z axes of the system are represented by CH_4/H_2, C_2H_2/C_2H_4 and C_2H_4/C_2H_6 ratios respectively. Values ranges of ratios make the use of a linear scale on axes these ratios represent inadequate. Thus a log scale with base 10 is used on each axe. For implementation purposes, the point $\boldsymbol{O}$ $(0.001, 0.001, 0.001)$ has been defined as the origin of the system. All the preceding points are illustrated in Figure 2.

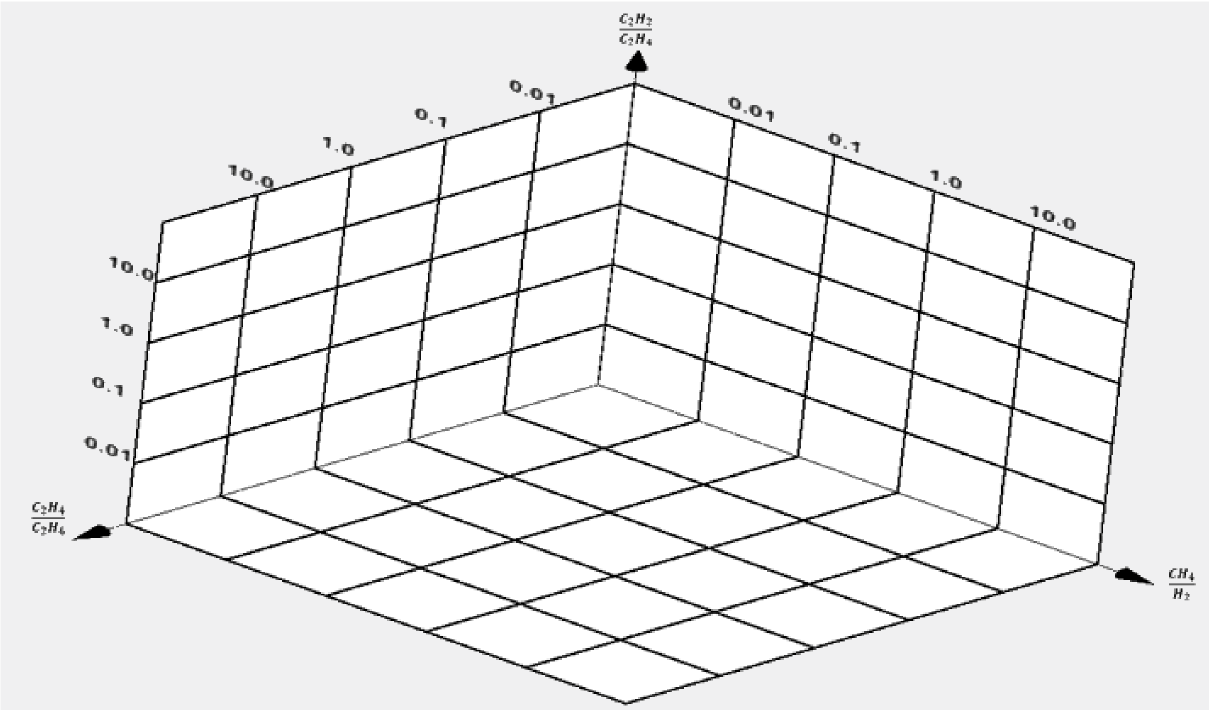

Figure 2. 3D space for three-ratio method graphical representation.

3.2 Representation of regions corresponding to fault types identified by the three-ratio method in the 3D space.

As shown in Table 3, the three-ratio method identifies 6 fault types (PD, D1, D2, T1, T2, and T3). Regions to which the fault types will be mapped correspond parallelepiped in the 3 dimensional space, parallelepiped whose boundaries will be computed according to ratios limit values on each on each axe as specified in Table 4. The construction of a regions is described by the following algorithm:

- **Step 1** : construct a cube of side length 1
- **Step 2** : along each axe of the space, scale the cube by a factor **Sfactor** computed as follow:

$$Sfactor = \begin{cases} \log_{10} \dfrac{max}{min} & If\ min > 0 \\ \log_{10} max & If\ min = 0 \end{cases} \quad \textbf{(1)}$$

where *min* and *max* represent the lower bound and upper bound of gases ratio respectively along each axe.

- **Step 3:** Position the obtained parallelepiped in the 3D system by applying a translation to it of vector ***V***. The components of this translation vector are given by the following formula:

$$V_i = \begin{cases} \log_{10} \frac{min_i}{10 * O_i} + 1 & If\ min > 0 \\ 0 & If\ min = 0 \end{cases} \quad \textbf{(2)}$$

where min_i is the lower bound of gases ratio respectively along the i[th] axe, and V_i the i[th] component of the translation vector.

3.3 Location of faults experienced by the transformer according to gases ratios' values.

Locating a potential issue undergone by the transformer in accordance to gases ratios values is done by using **(2)** to compute the components of the translation vector showing a point, in the 3D system, pertaining or not to regions corresponding to the different fault types.

Table 4 Rogers ratios limit values [5]

Fault case	Fault description	$\frac{C_2H_2}{C_2H_4}$	$\frac{CH_4}{H_2}$	$\frac{C_2H_4}{C_2H_6}$
PD	Partial discharge	≤ 0.01	≤ 0.1	≤ 0.2
D1	Discharge of low energy, arcing	> 1	$[0.1 - 0.5]$	> 1
D2	Discharge of high energy, arcing	$[0.6 - 2.5]$	$[0.1 - 1]$	> 2
T1	Thermal fault 150°C, conductor overheating	< 0.01	> 1	< 1
T2	Thermal fault 300°C–700°C, moderate oil overheating	< 0.1	> 1	$[1 - 4]$
T3	Thermal fault 700°C, severe oil overheating	< 0.2	> 1	> 4

4 3D graphical implementation of Rogers ratio in JAVA

The system we specified in the preceding section is developed in JAVA and presented in this section. The choice to develop such a system in the java programming language was motivated by its significance in computer graphics applications development and its popularity. JAVA runs on every environment where a JAVA Virtual Machine is installed, and possesses an important and active community of developers who develop free tools for a wide range of applications. One of the most noticeable tool to have emerged from this community is the JOGL library. The JOGL project is in charge of the development of the Java binding for the OpenGL library, and is designed to provide hardware-supported 3D graphics to applications developed in Java[8]. We make use of JOGL in the implementation of the 3D graphical representation of the Rogers ratio method. Based on openGL, JOGL does not however provide a system for windows creation and events handling. Fortunately JAVA offers many applications programming interfaces (API) that provide the developers with all the windowing system necessary for the creation rich user interfaces. Swing API is used for that purpose. Figure 3 illustrates an example of diagnosis using the developed software.

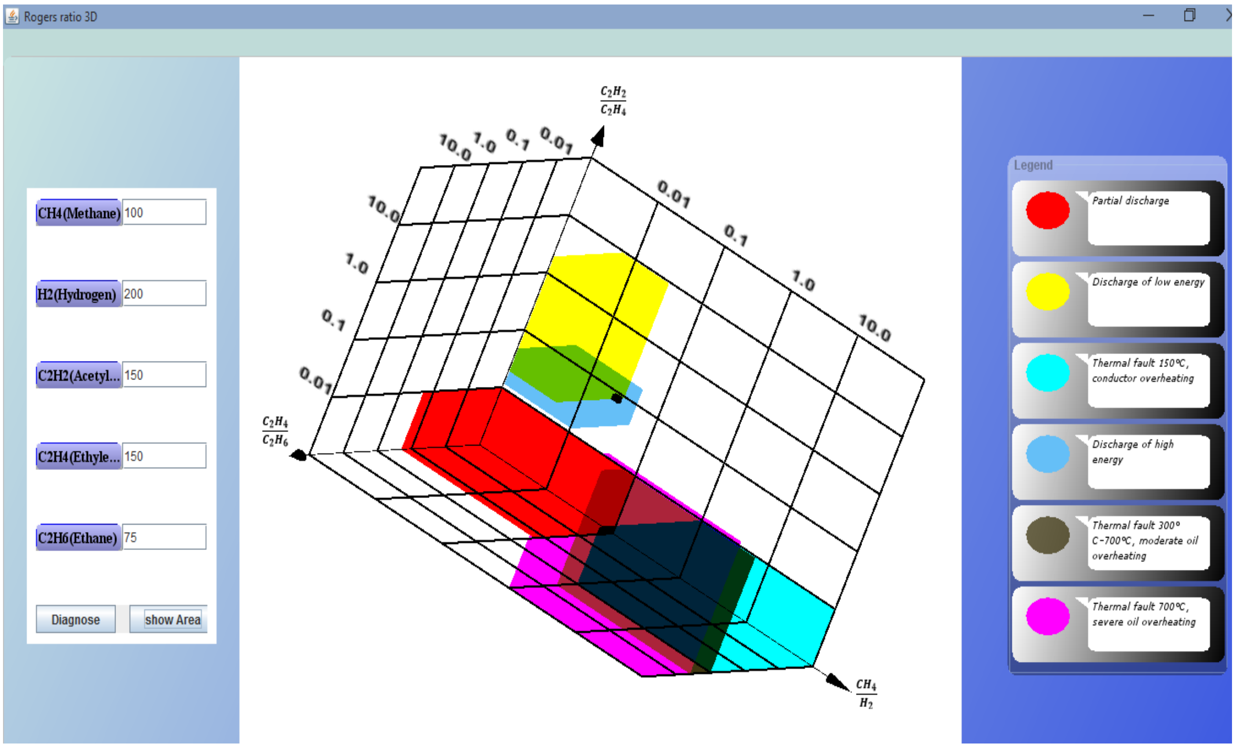

Figure 3 Example of a diagnosis by a 3D implementation of the Rogers Ratio in JAVA

5 CONCLUSION AND SUGGESTIONS

In this paper a 3D implementation of the Rogers ration method for dissolved gas in oil analysis was studied. This method is widely used by power utilities for DGA data analysis. The software we developed can be used as a standalone system or integrated in a more furnished set of DGA diagnostic tools that includes other DGA methods such as the Duval Triangle, Doernenburg ratios, or the Total dissolved combustible gas (TDCG). We can also think of the integration of this software into an infrastructure containing sensors, databases in other to set up system for oil insulated power transformers real time condition monitoring and assessment.

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