Dissolved Gas Analysis in transformer using Fuzzy Logic based on IEC Standard

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Abstract

Dissolved Gas Analysis (DGA) [1-4] of insulation oil in an oil insulated transformer is one of the most useful techniques for the detection of the incipient faults. The various methods, such as Gas key method, Ratios method, Graphical representation method are well known to interpret DGA results. When multiple fault exists in a transformer, these methods sometimes fail to diagnose. IEC This paper proposes a Fuzzy Three Ratio Method; it is considered that the drawbacks of the above mention Methods lies in: when the ratio crosses the coding boundary, codes change sharply, but in reality the boundary should be fuzzied[7]. This paper first propose the fuzzy membership functions for codes "zero", "one", "two", then it transfer the conventional logic "AND" and "OR" used in IEC three-ratio method into fuzzy logic and finds the diagnosing steps of this method. MATLAB based scripts prove that the proposed method can overcome the drawbacks of the above mention Methods that cannot diagnose multi-fault and no matching codes for diagnosis. In this paper a Fuzzy Logic based approach which can diagnose multiple faults is presented.

Keywords — *Transformer, DGA, fuggy three ratio method.*

I. INTRODUCTION

. The power system starts with generation, by which electrical energy is produced in the power plant and then transformed in the power station to high-voltage electrical energy that is more suitable for efficient long-distance transportation. High-Voltage (HV) power cables in the transmission of the electric power system efficiently transport electrical energy over long distances to the consumption locations. Transformers are an essential part of any electrical system. When there is an overheating inside a transformer, it will produce corresponding characteristic gas in the transformer oil, so dissolved gas in oil analysis (DGA) is most commonly used method to diagnose power transformer faults. Among DGA methods, the most commonly used is conventional IEC three ratio method. But this method cannot offer accurate diagnosis for all the faults. Through the combination of fuzzy logic and IEC three ratio method, this paper put forward fuzzy three ratio method. Simulation proves the proposed method can overcome the drawbacks of the three ratio methods. Thus, it greatly enhanced diagnosing accuracy [3].

Remainder of paper is organized as follows. Section II covers dissolved gas analysis method. Implementation details of proposed scheme are discussed in section III. We have simulated DGA in MATLAB. Simulation results are given in section IV.

II. DISSOLVED GAS ANALYSIS IN TRANSFORMER OIL

Transformer is an important component of electricity transmission and distribution. For reliable electricity supply it is necessary to give considerable attention to the maintenance of transformers. To maximize the lifetime and efficiency of transformers, it is important to be aware of possible faults that may occur on the transformer. These faults can lead to the thermal degradation of the oil and paper insulation in the transformer. The composition and quantity of the gases generated depend on the types and severity of the faults, and regular monitoring and maintenance can make it possible to detect incipient flaws before damage occurs.

The four main types of transformer faults are

- Arcing or high current breakdown,
- Low energy sparking, or partial discharges,
- Localized overheating, or hot spots, and
- General overheating due to inadequate cooling or sustained overloading.

The regular monitoring of dissolved gases can provide useful information about the condition of the transformer and prior information of the faults [7].

A. Dissolved Gas Analysis (DGA)

Dissolved gas analysis [6] is a test used as a diagnostic and maintenance tool for oil-filled apparatus. Under normal conditions, the oil present in a transformer will not decompose at a faster rate. However, thermal and electrical faults can increase the rate of decomposition of the dielectric fluid, as well as the solid insulation. Gases produced by this process are of low molecular weight and include hydrogen, methane, ethane, acetylene, carbon monoxide, and carbon dioxide, and these gases get dissolved in the oil. Abnormal conditions in a transformer can be detected early by analyzing the gases that get evolved within it. Analyzing the specific proportions of each gas helps in identifying faults. Faults detected in this way may include processes such as corona, sparking, overheating, and arcing. If the right preventive measures are taken early in the detection of these gases, damage to equipment can be minimized. Although various techniques are available for maintenance and fault diagnosis in power transformers, DGA is far superior to all other methods because it provides very useful data on the electrical and thermal abnormalities within transformers in operation. Most of the faults of a transformer can be easily diagnosed by DGA from the collected oil sample.

B. *Methods of interpreting fault using DGA:*

1) *Key Gas method*

In this method the concentration and gassing rates of the key hydrocarbon gases is monitored. The key gases analyzed are, hydrogen (H2), methane (CH4), ethane (C2 H6), ethylene (C2 H4), acetylene (C2H2). carbon monoxide (CO), and carbon dioxide (CO2). The concentrations are expressed in ppm (parts per million). The normal operating concentration of these key gases according to IEC 60599 is given in the table 1.

Table 1: Dissolved gas composition

H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO	CO_2
60-150	40-110	50-90	60-280	3-50	540-900	5100-13000

2) *Ratio Method:*

This method is the most widely used method for the fault interpretation. In this method ratios of gas concentrations are used for the interpretation purpose. Roger ratio method, Dorrenburg ratio method, and IEC ratio methods are used by the utilities. IEC ratio method is used as an industry standard. Fault type classification shown in table2.

TABLE 2: Fault classifications according to the IEC gas ratio codes

No.	Fault type	$\frac{C_2H_2}{C_2H_4}$	$\frac{CH_4}{H_2}$	$\frac{C_2H_4}{C_2H_6}$
1	No fault	0	0	0
2	Partial discharges of low energy density	0	1	0
3	Partial discharges of high energy density	1	1	0
4	Discharges of low energy density	1 or 2	0	1 or 2
5	Discharges of high energy density	1	0	2
6	Thermal fault of low temperature <150˚C	0	0	1
7	Thermal fault of low temperature 150˚-300 ˚ C	0	2	0
8	Thermal fault of medium temperature 300 ˚- 700˚C	0	2	1
9	Thermal fault of high temperature >700 ˚C	0	2	2

III. IMPLEMENTATION

Fuzzy Logic based Fuzzy Three Gas Ratio method is studied and implemented using MATLAB application software [5].

A. *Fuzzy Three Gas Ratio Method*

The combination of fuzzy logic and IEC Three Ratio method, this project puts forward Fuzzy Three Ratio Method. It fuzzifies the coding boundary, thus overcomes the drawbacks of changing coding boundary.

1) *The Fuzzification of the Three-Ratios*

According to Table 2, three gas ratios, R1 = Acetylene (C2H2) / Ethylene (C2H4), R2 = Methane (CH4) / Hydrogen (H2), and R3 = Ethylene (C2H4) / Ethane (C2H6); can be coded as 0, 1, and 2 for different ranges of ratios.

According to Table 3, specific codes of three gas ratios correspond to specific fault. For instance when transformer is diagnosed as no.8 fault, R1 =0, R2 = 2, and R3 = 1. In the IEC code diagnosis, actually the conventional logic AND and OR are used. For example: R1 = 0 AND R2 = 2 AND R3 = 1, through conventional logic operation, will be either one (true) or zero (false).

This method holds that the drawback of the conventional IEC method lie in that when gas ratio change across coding boundary, the code change sharply between 0, 1, and 2. In fact, the gas ratio boundary should not be clear (i.e. fuzzy).

In this method, IEC codes 0, 1, 2 are replaced by fuzzy sets ZERO, ONE, TWO, each gas ratio can be represented by a fuzzy vector [μ ZERO (R), μ ONE (R), μ TWO (R)], where μ ZERO (R), μ ONE (R), μ TWO (R)are the membership function of the fuzzy set ZERO, ONE, TWO.

In the following, R1 is taken as an example to explain how to transfer IEC codes 0, 1, 2 into fuzzy set ZERO, ONE, and TWO. [4]

The membership function of fuzzy set ZERO is:

μ ZERO (R1) = 1 R1 ⩽ 0.08

= e-50 (R1 - 0.08) R1 > 0.08

The membership function of fuzzy set ONE is: μ ONE (R1) = 0 R1 ⩽ 0.08

= 0.5 + 0.5 sin (25 Π (R1 - 0.1)) R1 ϵ (0.08, 0.12)

= 1 R1 ϵ (0.12, 2.9)

= 0.5 - 0.5 sin (5 Π (R1 - 3)) R1 ϵ (2.9, 3.1)

= 0 R1 > 3.1

The membership function of fuzzy set TWO is: μ TWO (R1) $= 0 \quad R1 \leqslant 2.85$

$= e^{-12} (R1 - 2.85) \quad R1 > 2.85$

Similarly, the three fuzzy membership functions for R2 can be obtained as follows:

The membership function of fuzzy set ZERO is: μ ZERO (R2) $= 0 \quad R2 \leqslant 0.08$

$= 0.5 + 0.5 \sin (25 \Pi (R2 - 0.1))$ R2 ϵ (0.08, 0.12)

$= 1$ R2 ϵ (0.12, 0.9)

$= 0.5 - 0.5 \sin (5 \Pi (R2 - 1))$ R2 ϵ (0.9, 1.1)

$= 0 \quad R2 > 1.1$

The membership function of fuzzy set ONE is: μ ONE (R2) $= 1 \quad R2 \leqslant 0.08$

$= e^{-50} (R2 - 0.08) \quad R2 > 0.08$

The membership function of fuzzy set TWO is: μ TWO (R2) $= 0 \quad R2 \leqslant 0.85$

$= e^{-12} (R2 - 0.85) \quad R2 > 0.85$

Similarly, the three fuzzy membership functions for R3 can be obtained as follows:

The membership function of fuzzy set ZERO is: μ ZERO (R3)$= 1 \quad R3 \leqslant 0.85$

$= e^{-50} (R3 - 0.08) \quad R3 > 0.85$

The membership function of fuzzy set ONE is: μ ONE (R3) $= 0 \quad R3 \leqslant 0.9$

$= 0.5 + 0.5 \sin (25 \Pi (R3 - 1))$ R3 ϵ (0.9, 1.1)

$= 1$ R3 ϵ (1.1, 2.9)

$= 0.5 - 0.5 \sin (5 \Pi (R3 - 3))$ R3 ϵ (2.9, 3.1)

$= 0 \quad R3 > 3.1$

The membership function of fuzzy set TWO is: μ TWO (R3) $= 0 \quad R3 \leqslant 2.85$

$= e^{-12} (R3 - 2.85) \quad R3 > 2.85$

2) *The Steps of Diagnosing Fuzzy Three Ratio Method*

Step-1: From the DGA report of the input oil sample, provide the values of concentration of different gases like Hydrogen (H_2), Methane (CH_4), Ethane (C_2H_6), Ethylene (C_2H_4) and Acetylene (C2H2) in ppm.

Step-2: Calculate three ratios R1,R2 ,R3.

Step-3: Calculate the three fuzzy membership functions of each ratio based on equations listed in section III.

Step-4: As for the conventional logic "AND" and "OR" used in the conventional IEC diagnosis, replace "AND" by "min", "OR" by "max", the fuzzy diagnosing vector $F(i)$ where $i = 1, 2,\ldots,9$ represent i^{th} fault in Table 3 is determined by the following equations:[4][1]

F (1) = min [μ_{ZERO} (R1), μ_{ZERO} (R2),μ_{ZERO} (R3)]

F (2) = min [μ_{ZERO} (R1), μ_{ONE} (R2),μ_{ZERO} (R3)]

F (3) = min[μ_{ONE} (R1), μ_{ONE} (R2), μ_{ZERO} (R3)]

F (4) = max (min [μ_{ONE} (R1), μ_{ZERO} (R2), μ_{ONE} (R3)]
min [μ_{TWO} (R1), μ_{ZERO} (R2), μ_{ONE} (R3)]
min [μ_{TWO} (R1), μ_{ZERO} (R2), μ_{TWO} (R3)])

F (5) = min [μ_{ONE} (R1), μ_{ZERO} (R2), μ_{TWO} (R3)]

F (6) = min [μ_{ZERO} (R1), μ_{ZERO} (R2), μ_{ONE}(R3)]

F (7) = min [μ_{ZERO} (R1), μ_{TWO} (R2), μ_{ZERO}(R3)]

F (8) = min [μ_{ZERO} (R1), μ_{TWO} (R2), μ_{ONE} (R3)]

F (9) = min [μ_{ZERO} (R1), μ_{TWO} (R2), μ_{TWO} (R3)]

Step-5: Fault type out of the listed faults in table2 is determined.

IV. SIMULATION RESULTS

In order to prove the accuracy of the fuzzy three ratio proposed in this paper, 12 samples with actual fault type already known are collected. Simulation is then carried out by using MATLAB. The diagnosing steps are mention in section Simulation results are shown in table 3. From the table 3, the accuracy of fuzzy method is about 91.66% for readings under consideration.

Table 3: DGA Samples And Diagnosis Results by Different Methods

SR. No.	H2	CH4	C2H6	Ethylene C2H4	Acetylene C2H2	Actual Fault Type	Fuzzy Three Ratio Method
01	200	700	250	740	1	8,9	8,9
02	300	490	180	360	95	8	8
03	62	372	208	1658	10	9	9
04	176	205.9	47.7	75.7	68.7	4	8
05	16	8	7	1	0	1	1,2
06	305	100	33	161	541	4	4
07	3700	1690	128	2810	3270	5	5
08	206	198.9	74	612.7	15.1	9	9
09	27	12	19	125	65	5	5
10	1270	3450	520	1390	8	8	8
11	10	64	12	117	11	9	9
12	19	80	340	28	1	7	7

V. CONCLUSION

It has been proved that using the fuzzy three ratio method, more information about the faults inside a transformer can be obtained. In addition to providing enhanced information for the maintenance engineer while remaining faithful to the original method and determining the fault in transformer. The recommended and the advisable actions are demonstrated in the program for this method. Also, the multiple faults can be diagnosed using this method, while, it may not be possible for any conventional method.

This paper describes a transformer fault diagnose method based on Fuzzy Three Ratio Method. This method can overcome the drawbacks of the Conventional Method. The programming of fuzzy logic is easy as compared to other conventional method. Simulation results show the program work well and the accuracy of the fuzzy logic method is much higher than the Conventional Method.

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