A Modified Dissolved Gas Analysis Technique as a Diagnostic Tool for Faults in Power Transformers

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***Abstract*— Dissolved Gas Analysis (DGA) is one of the most common methods used to diagnosis the fault types in the transformers. The fault types which occur in the power transformer are categorized as partial discharge, low discharge energy, high discharge energy, low thermal fault, medium thermal fault and high thermal fault. These faults can be specified according to the concentrations of each dissolved in the transformer oil. In this paper, the modified technique result depends on the outputs of the three techniques (new approach, conditional probability, Duval). The modified technique was prepared to increase the accuracy of the detection of the transformer fault types. It was constructed based on 386 samples that were collected from the Egyptian Electricity Transmission company (EETC) – Central Chemical Laboratories, and were known their actual faults. The result of the modified DGA technique indicated an increase of the diagnostic accuracy rather than the other DGA techniques.**

Keywords— dissolved gas analysis (DGA), a new approach, conditional probability technique, Duval method, modified technique.

I. Introduction

Mineral oil is an insulating medium to provide the necessary cooling and isolating the transformer components. In the transformer, during the normal condition, some of combustible gases such as Hydrogen, Methane, Acetylene, Ethylene, Ethane, Carbon monoxide and Carbon Dioxide are released at low concentrations. Under fault conditions, these gases with high concentration levels are released and are given information on transformer condition, fault type and instructions on future operation. Six types of transformer faults are categorized as (partial discharge (PD), low and high discharge energy (D1, D2) respectively and low, medium and high thermal fault (T1, T2, T3) respectively. The most common five methods that are used to diagnosis the transformer fault types are (key gas, Dornenburg, Rogers, Duval Triangle and IEC standard) methods. These methods depend upon the using of gases ratio to diagnosis the fault types, and compare with the specified levels of gas concentrations to state evaluate the transformers oil [1]. The advantage of these methods is simple in implementation, but their diagnostic accuracy is low and very sensitive to uncertainties in DGA data. In addition to, these diagnostics methods don't always yield an analysis, miss too many incipient faults and may lead to the "no decision" problem [2].

In this paper, the modified technique is developed based on the output of three techniques (new approach, conditional probability and Duval), to increase the accuracy of the fault types detection and analysis in the transformers. It was constructed based on 386 samples that were collected from the Egyptian Electricity Transmission company (EETC) – Central Chemical Laboratories, and were known their actual faults.

II. The Modified Technique

The modified technique depends on the combination of the most well-known DGA interpretation techniques, such as:

- New approach technique.
- Conditional probability technique.
- Duval method.

The following section explains these techniques, and their approaches.

A. New Approach Technique.

A new approach technique is constructed based on the percentage of the main five dissolved gases [Hydrogen (H_2), Acetylene (C_2H_2), Methane (CH_4), Ethane (C_2H_6) and Ethylene (C_2H_4)] with respect to their total. Each fault is determined, based on the limit of each gas concentricity percentage and some of the proposed gas ratios. Fig. 1 (a, b, c, d, e and f) shows the concentricity percentage of each gas in the cases of fault types [3, 4]. The limits of each fault type in this technique are determined as showing in Table I.

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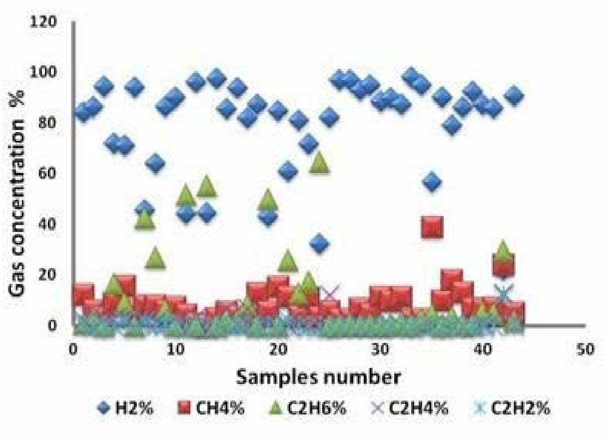

Fig. 1. (a) The concentricity percentage of each gas in the case of PD fault

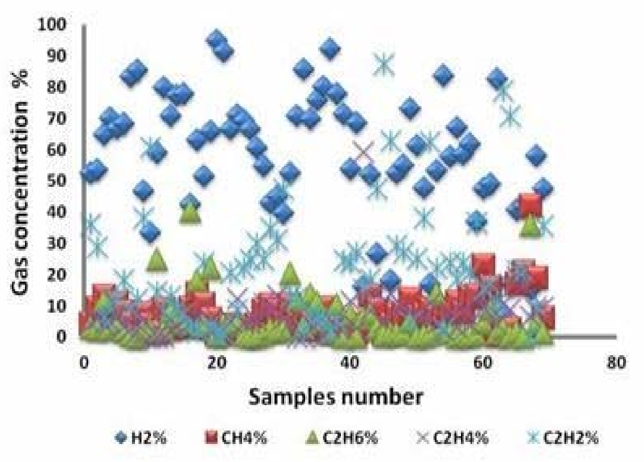

Fig. 1. (b) The concentricity percentage of each gas in the case of D1 fault

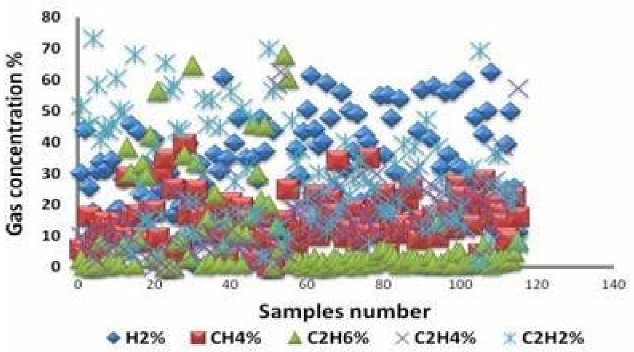

Fig. 1. (c) The concentricity percentage of each gas in the case of D2 fault

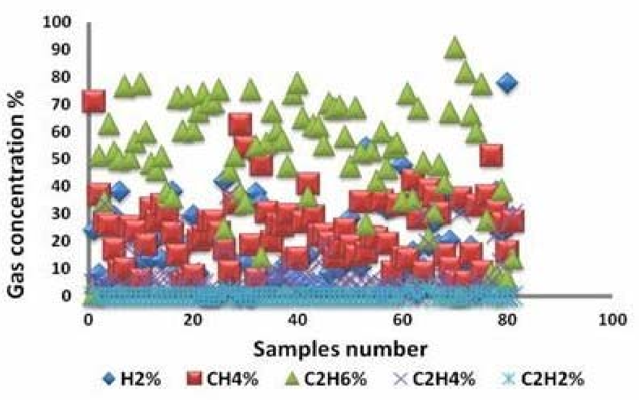

Fig. 1. (d) The concentricity percentage of each gas in the case of T1 fault

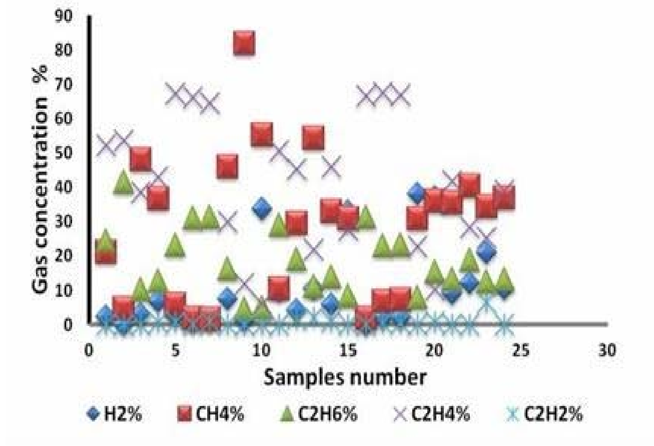

Fig. 1. (e) The concentricity percentage of each gas in the case of T2 fault

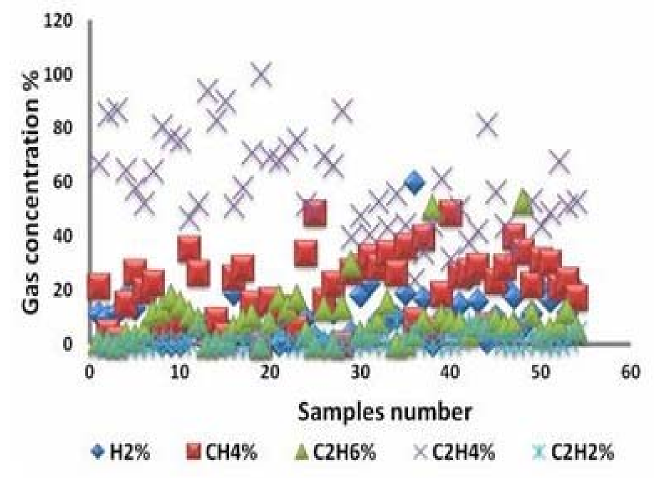

Fig. 1. (f) The concentricity percentage of each gas in the case of T3 fault

Fig. 1 shows the distribution of the gases concentricity percentage according to the sample numbers for each fault types. The samples number is represented on the horizontal axis and the vertical axis represented the percentage gas concentration based on main five gases (Hydrogen, Acetylene, Methane, Ethane and Ethylene). This technique is indicates the transformer fault types (partial discharge (PD), low discharge energy (D1), high discharge energy (D2), low thermal fault (T1), medium thermal fault (T2) and high thermal fault (T3)) based on the gases concentricity percentage. The steps of this technique are as follows [3]:-

1. Collect the data of the dissolved gas.
2. Calculate the summation of the main five gases during the fault (Hydrogen (H_2), Acetylene (C_2H_2), Ethane (C_2H_6), Ethylene (C_2H_4), and Methane (CH_4)).This sum is defined as Total Combustion Gases (TCG).
3. Calculate the Gas concentricity percentage (GCP) as in the following equation:-
   Gas concentration percentage = (H_2/TCG, C_2H_2/TCG, C_2H_6/TCG, C_2H_4/TCG, CH_4/TCG) %.
4. According to the concentration percentage for each gas, the transformer fault type can be determined as in Table I.

TABLE I. THE LIMITS OF A NEW APPROACH DGA TECHNIQUE

Fault type	PD	D1	D2	T1	T2	T3
H2 %	30 -90	10 -96	≤ 61	≤ 50	≤ 25	≤ 35
CH4%	≤ 18	≤14.5	≤ 40	≤ 80	≤ 83	≤ 50
C2H6%	≤ 66	≤ 42	≤70	≤ 100	4 - 90	≤ 20
C2H4%	≤ 13	≤ 5	≤ 35	≤ 40	10-70	30 -100
C2H2%	≤ 2.5	≤ 40	≤ 80	≤ 4	≤ 2	≤ 12

B. Conditional Probability Technique

This technique is used to diagnose transformer fault types according to the percentage of the main five gases [Hydrogen, Acetylene, Methane, Ethane and Ethylene] with respect to their total. According to the fault features, the point probabilities of each fault type occurrence and non-occurrence are determined. Then, the probabilistic indication of each fault type occurrence can be specified according to the conditional probability of certain fault occurrence. Multivariate normal probability function is investigated to indicate the conditional probability of the fault occurrence. For each fault type, dissolved gases concentration is distributed with randomly. The approximation of these gases which dissolved can be achieved by a Gaussian theory. Then, this probability technique is employed to detect the incipient faults in the transformers as clarified in this paragraph. The probability technique is applied to the fault features taken away from the dissolved gases analysis. The most common five gases are inspected for indicating 6 main transformer fault types. These five dissolved gases are H_2, C_2H_6, C_2H_4, C_2H_2, and CH_4 where their concentricity is computed as a percentage with respect to their total sum. G_i refers to gases (i= 1, 2, 3, 4, 5) and F_j refers to transformer faults (j = 1, 2, 3, 4, 5, 6). And, there are sundry inputs to the probability, multivariate normal probabilistic density function is considered to point out the conditional probability of the occurrence of the transformer fault and can be calculated as in (1) [5]:-

$$f_{1j} = \frac{e^{(-1/2)(G_i\% - \mu_{1i})\, \sigma_{1i}{}^{-1}(G_i\% - \mu_{1i})}}{\sqrt{|\sigma_{1i}|(2\pi)^m}} \quad (1)$$

Where the vector μ_{1i} is a mean deviation and the vector σ_{1i} is a standard deviation, m refers to the number of input variables and G_i % is the gas concentration percentage, and is given as in (2):-

$$G_i\,\% = \frac{G}{G_t}\,100\% \quad (2)$$

Where, the gas concentricity of a certain gas is represented by G_i, and the sum of the main five gases is represented by G_t.

Equation (3) shows the density function of the multivariate normal distribution for the non-occurrence of the transformer fault of index j as the following:-

$$f_{0j} = \frac{e^{(-1/2)(G_i\% - \mu_{0i})\, \sigma_{0i}{}^{-1}(G_i\% - \mu_{0i})}}{\sqrt{|\sigma_{0i}|(2\pi)^m}} \quad (3)$$

The index j refers to the six common fault types (PD, D1, D2, T1, T2 and T3) respectively. According to the conditional probability theorem, the selectivity function which used to indicate the fault types is given as follow in (4) [5]:-

$$P_r(Fault\ type\ j|G_1\%, \cdots G_i\%, \cdots G_5\%) = \frac{\frac{f_{1j}(G_i\%)}{f_{0j}(G_i\%)}}{\sum_{k=1}^{n} \frac{f_{1k}(G_i\%)}{f_{0k}(G_i\%)}} \quad (4)$$

Where,' k is a counter up to n that is the total number of fault types considered with the probability density function. The above equation is calculated six times to estimate each fault type occurrence. Then, the final output is a vector indicating the probabilities of the various fault types. The diagnostic is the fault type corresponding to the maximum probability. Then, the identification of faults type (PD, D1, D2, T1, T2, and T3) is the final objective of the proposed algorithm in conditional probability technique. There are two steps to determination the transformer faults as follows:-

- The transformer fault is categorized as partial discharge (PD), arcing (AR) or thermal (TH).
- The intensity of the fault, either electrical or thermal, is determined according to Fig. 2 [5].

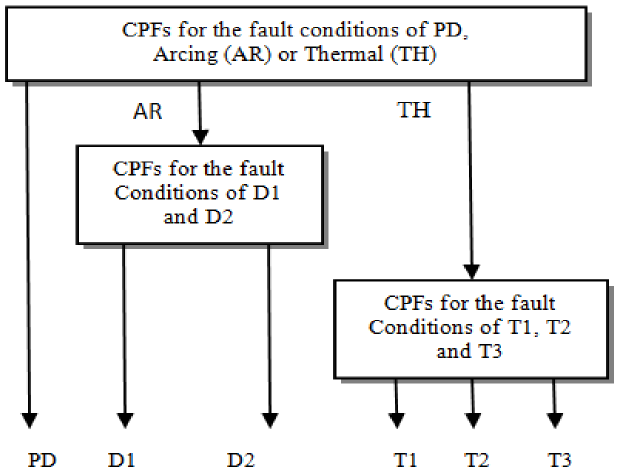

Fig. 2. The fault types determination using conditional probability technique

C. Duval Method

This method is constructed based on the concentration of three dissolved gases CH_4, C_2H_4, and C_2H_2. Generally, in Duval triangle, six zones are categorized as (PD, D1, D2, T1, T2 and T3) faults type, in addition (DT) zone has been referred to admixture of thermal and electrical faults as in

Fig. 3 [6, 7&8]. The approach of this method is at least one of the gas values exceed a specified limit in Table II in order to be considered as having a fault [8].

TABLE II. THE GASES LIMITS [8]

Dissolved gases	H2	CH4	C2H2	C2H4	C2H6	CO	CO2
Limits	100	75	3	75	75	700	7000

In order to detect the transformer faults using Duval triangle, the sum of the three Duval Triangle gases (CH4, C2H2 and C2H4) is calculated and each of these gases is divided by their sum to find the percentage of each gas of the sum according to the following equations [8]:-

R1= (CH4%) / (CH4+C2H4+C2H2), (5)

R2= (C2H4%) / (CH4+C2H4+C2H2), (6)

R3= (C2H2%) / (CH4+C2H4+C2H2). (7)

According to the values of (5), (6) and (7), the transformer fault type can be determined as in Table III.

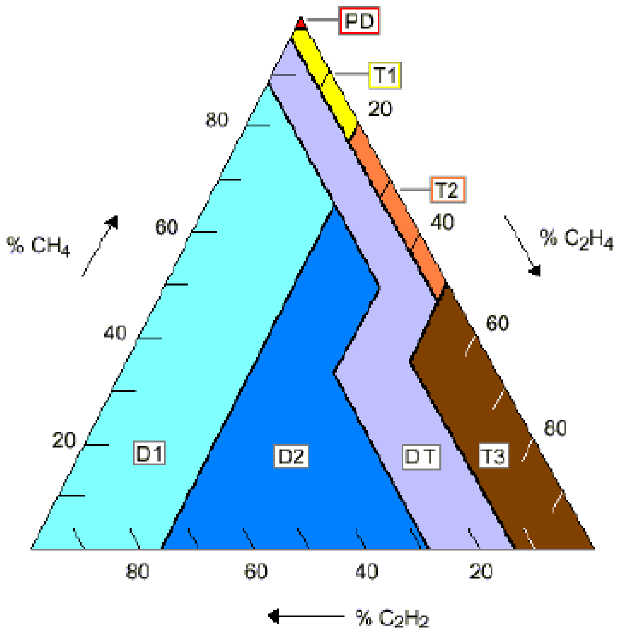

Fig. 3. The Duval triangle [5]

TABLE III. THE DUVAL METHOD RATIOS [9, 10]

Fault type	Ratio
PD	R1 ≥ 98, R2 ≤ 2 & R3≤ 2
D1	R3 ≥ 0 & R2 ≤ 23
D2	(13 ≤ R3 ≤ 79 & R2 ≤ 77) or (4 ≤ R3≤ 29 & R2 ≤ 85)
T1	R3 ≤ 4, R2 ≤ 20 & 76 ≤ R1 ≤ 98
T2	R3 ≤ 4 , 20 ≤ R2 ≤ 50 & 46 ≤ R1 ≤ 80
T3	R3 ≤ 15 , R2 ≥ 50 & R1 ≤ 50

III. THE PROPOSED OF THE MODIFIED TECHNIQUE FOR DGA

The modified technique is processed in the MATLAB software [11, 12]. This modified technique is constructed based on determining the diagnosis of three DGA techniques (Duval, new approach and conditional probability techniques). This technique depends on the results of the above three techniques and their success in detecting the transformer fault types. The modified DGA technique is constructed to improve the accuracy of the transformer faults detection by using the outputs diagnosis fault of the three DGA techniques (new approach, conditional probability and Duval). The out1, out2 and out3 indicate the diagnosis results by the new approach, conditional probability and Duval techniques respectively, and the inputs to the modified technique are the output diagnoses from these techniques.

Fig. 4 shows the flowchart of the modified DGA technique which indicates the procedures of this technique by using the outputs of the three techniques.

The following steps explain how the modified output result can be obtained:-

1. When the Duval technique and conditional probability technique and new approach technique output diagnosis or only two of output diagnosis are similar to each other and give PD fault type then the diagnosis fault is PD.
2. When the Duval technique , conditional probability technique and new approach technique output diagnosis or only two of output diagnosis are similar to each other and give D1 fault type then the diagnosis fault is D1.
3. When the Duval technique , conditional probability technique and new approach technique output diagnosis or only two of output diagnosis are similar to each other and give D2 fault type then the diagnosis fault is D2.
4. When the Duval technique , conditional probability technique and new approach technique output diagnosis or only two of output diagnosis are similar to each other and give T1 fault type then the diagnosis fault is T1.
5. When the Duval technique , conditional probability technique and new approach technique output diagnosis or only two of output diagnosis are similar to each other and give T2 fault type then the diagnosis fault is T2.
6. When the Duval technique , conditional probability technique and new approach technique output diagnosis or only two of output diagnosis are similar to each other and give T3 fault type then the diagnosis fault is T3.
7. When the Duval technique, conditional probability technique and new approach technique output diagnosis are different from each other, therefore, the modified output will be as the diagnosis of the conditional probability technique due to its high accuracy with compare to the two other techniques (Duval and new approach).

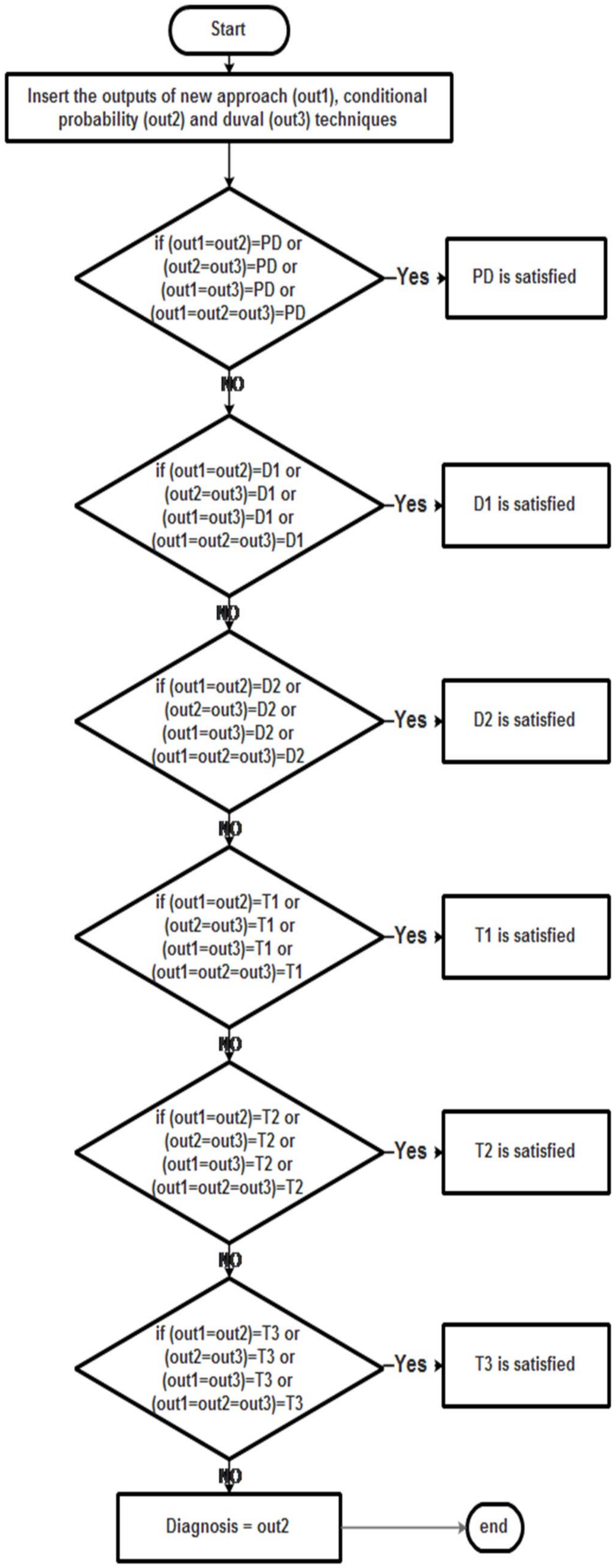

Fig. 4. Flowchart of the modified DGA technique

Fig. 5 shows the comparison between the accuracy of the three DGA techniques (new approach, conditional probability and Duval Triangle) and the accuracy of the modified technique. The results of the modified DGA technique indicated an increase of the diagnostic accuracy rather than the other DGA techniques.

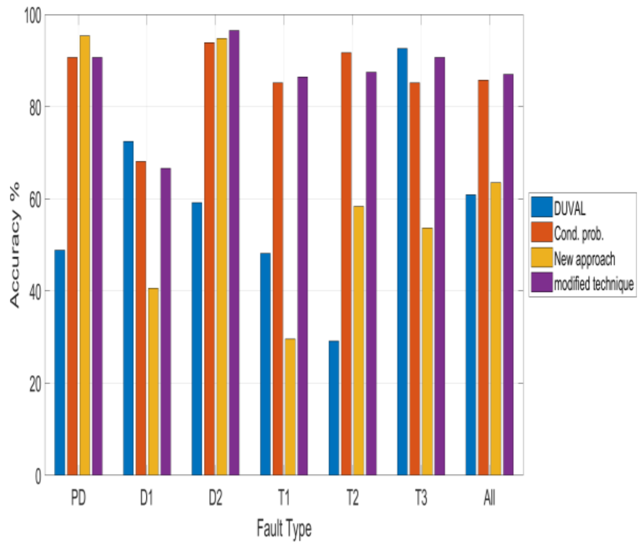

Fig. 5. Percentage accuracy according to actual fault types for DGA interpretation techniques (386 samples)

The accuracy of diagnosis D2 fault type is improved from 59.13% for Duval and 93.91% for conditional probability and 94.78% for new approach technique to 96.52% for the modified technique, and the accuracy of diagnosis T1 fault type is improved from 48.14% for Duval and 85.18% for conditional probability and 29.62% for new approach technique to 86.41% for the modified technique.

Table IV summarizes the comparison between the accuracy percentage of modified technique, conditional probability and new approach as Duval results. The accuracy is improved from 60.88% for Duval and 85.7512% for conditional probability and 63.47 for new approach technique to 87.0466% for the modified technique.

TABLE IV. THE COMPARISON BETWEEN THE % ACCURACY OF MODIFIED, CONDITIONAL PROBABILITY AND NEW APPROACH AS DUVAL RESULTS

Fault type	Actual No	Techniques accuracy percentage			
		Duval	*Cond_prob*	*New approach*	*Modified*
PD	43	48.83	90.69	95.34	90.69
D1	69	72.46	68.11	40.57	66.66
D2	115	59.13	93.91	94.78	96.52
T1	81	48.14	85.18	29.62	86.41
T2	24	29.16	91.66	58.33	87.50
T3	54	92.59	85.18	53.70	90.74
ALL	386	60.88	85.75	63.47	87.04

The three criteria agreement accuracies are 60.88%, 85.75%, and 63.47% for Duval Triangle Method, conditional probability, and new approach, respectively. The modified accuracy is better than these three techniques. A comparison between the three techniques and modified technique for different fault types is explained in Table IV and Fig. 5. These results explain the modified technique ability to detect the fault types.

Fig. 5 and Table IV show that the accuracy of diagnosis D2 fault type is improved from 59.13% for Duval and 93.91% for conditional probability and 94.78% for new approach technique to 96.52% for the modified technique, and the accuracy of diagnosis T1 fault type is improved from 48.14% for Duval and 85.18% for conditional probability and 29.62% for new approach technique to 86.41% for the modified technique. Finally, the results of the proposed modified model give a great importance and explain its ability to diagnose the transformer fault types.

IV. CONCLUSION

This paper proposes a modified technique of DGA diagnosis for the fault in mineral oil for power transformers had been made by conditional probability and Duval and a new approach technique to improve the accuracy. This modified technique is based on actual faults of the 386 dataset samples. Five main diagnosis gases H2, CH4, C2H6, C2H4 and C2H2 are selected from dissolved gases generated in transformers by using different gas ratio. The accuracy enhancement had been obtained using the modified technique. The overall accuracy improved from 60.88% for Duval, 85.7% for conditional probability and 63.4% for new approach to 87.1% for the modified technique.

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