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COMPARATIVE ANALYSIS USING VARIOUS DISSOLVED GAS ANALYSIS METHODS TO DETERMINE TRANSFORMER FAULT

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ABSTRACT
This paper investigates the accuracy and reliability of each Dissolved Gas Analysis (DGA) method via dissolved gases. Key Gas Method, Doernenburg Ratio Method, Rogers Ratio Method, IEC Ratio Method, and Duval Triangle Method are used to test the 100 sample units. The results obtained are Doernenburg and IEC 94% accuracy each, Duval Triangle 80% accuracy, Rogers 79% accuracy, and Key Gas 75% accuracy. The said individual ratio methods are combined to proceed with newly developed hybrid testing methods that could probably improve the existing DGA methods. The first hybrid method is a combination between Doernenburg and Rogers which produced a slight improvement of 86% accuracy. Then a combination between Doernenburg and IEC delivered a stable prediction result of 94%. It seems that Doernenburg and IEC are the most accurate Dissolved Gas Analysis methods. Although both methods are combined, they still produced a constant accuracy result. While the other methods, such as Key Gas, Rogers, and Duval Triangle, do not achieve satisfactory results.

Keywords: DGA interpretation, Fault diagnosis, Insulation medium

1. INTRODUCTION

The power transformer is an important equipment used in the generation and distribution of electricity. The most common type of distribution transformer used in utility systems is the liquid immersed type. As it is widely used outdoor, it has benefits of being smaller in size, less expensive, and has improved overload capabilities (Heathcote, 1998; Won, 1995). The power transformer is very dependable equipment that can last-long if it is properly handled and controlled. The failure in the transformer's service life requires expensive repairs and prolonged downtime. As such it is important to maintain insulation oil in good working condition to minimize repair costs and loss of time.

DGA is one of the most useful basic diagnosis methods for the detection of incipient fault (Ayalew et al., 2018; Desouky et al., 2016; Etman et al., 2017; Ghoneim et al., 2019; Lelekakis et al., 2011; Muhamad et al., 2007; Sarma & Kalyani, 2004; Shanker et al., 2018; Suleiman et al., 2012). CO, H_2, CH_4, C_2H_6, C_2H_4, and C_2H_2 are all typically gases measured in DGA studies. The advantages of DGA are:

1. Forewarning of developing faults
2. Monitoring rate of fault development
3. Confirming presence of faults
4. Convenient for repair scheduling
5. Checking condition during an overload

Even though DGA providing prior information on insulation medium condition, their accuracy and reliability in interpreting transformer condition are still arguable.

This paper focuses on investigating the health of transformer using all five conventional DGA methods as references and two newly proposed hybrid methods. Besides the accuracy and reliability of each method are studied with different type of DGA data by using MATLAB software.

2. LITERATURE REVIEW

2.1 Mineral Oil Decomposition

Mineral oil has been used as insulating medium for power transformer for a very long time. Mineral oil is a mixture of hydrocarbon molecules with a general formula of C_nH_{2n+2}, with n ranging from 20 to 40 in the form of paraffinic or aromatic compounds as shown in Fig.1 (Heathcote, 1998; Vahidi & Teymouri, 2019).

When mineral oil decomposes, gas molecules will release H_2, CH_4, C_2H_6, C_2H_4, and C_2H_2 (Vahidi & Teymouri, 2019).

Decomposition in mineral oil can be categorized into two categories, which are:

1. *Cellulose Decomposition*

Thermal degradation of cellulose involves three basic mechanisms, which are hydrolysis, oxidation, and pyrolysis (Lelekakis et al., 2011). All these mechanisms will form CO and CO_2, as well as H_2 and CH_4 (Digiorgio & Copyrighted, 2013; Lelekakis et al., 2011).

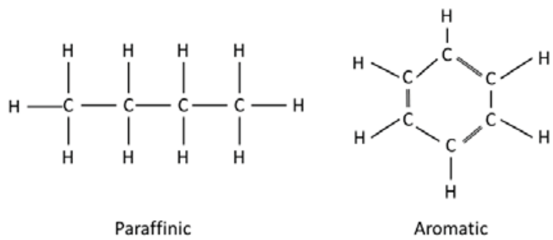


Fig.1 Molecular structure of hydrocarbon.

2. Oil Decomposition
The breaking of Carbon-Hydrogen and Carbon-Carbon bonds are the main cause formation of fault gases. These free radicals will combine H_2, CH_4, and C_2H_6. If mineral oils undergo further decomposition, resulting in the formation of C_2H_4 and C_2H_2 (Digiorgio & Copyrighted, 2013).

2.2 Gas Analysis Interpretation

The main causes of fault that affect the efficiency of insulation oils are:
1. Thermal Faults
a. Inside mineral oil
At temperature 150 to 500°C, small amount of low molecular weight gases (H_2, CH_4) and high molecular weight gases (C_2H_6, C_2H_4) are released (Sarma & Kalyani, 2004). If temperature exceeds 500°C, large amount of C_2H_2 is released.
b. Inside paper insulation or other solid insulation
Gases such as CO and CO_2 are released (IEEE, 2019).
2. Electrical Faults
a. Partial discharge
Partial discharge is dielectric breakdown of solid or liquid that produces large amount of H_2 and CH_4. Due to the mineral oil is stressed by high voltage, the bubbles or voids will be formed, discharges of cold plasma, and formation of X-wax will occur in the paper (Digiorgio & Copyrighted, 2013).
b. Arcing
Arcing is electrical breakdown of gas that resulting from high current released through non-conductive medium such as air. Arcing fault is the most serious fault because it generates large amount of C_2H_2 and developing discharges of ongoing plasma.

2.3 Diagnosis Method

Key Gas, Doernenburg ratio, Rogers ratio, IEC ratio, and Duval Triangle are the five conventional methods that involve in DGA. Each method has its own set of advantages and disadvantages, and not all types of DGA data ranges can be analyzed for all methods.

2.3.1 Key Gas Method (KGM)

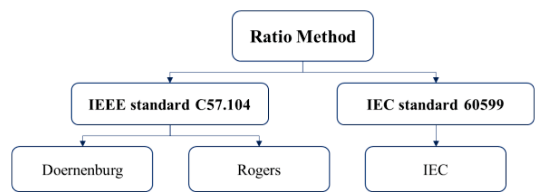
KGM depends on the number of fault gases emitted from insulating oils as the chemical structure that breaks down at different temperatures. To diagnose faults, only the highest number of main gas concentration is used instead of ratios. Table 1 summarizes the key gases produced by faults.

Table 1 Key Gas Method (IEEE, 2019).

Key Gas	Fault Type
C_2H_4	Thermal oil
CO	Thermal cellulose
H_2	Partial discharge
C_2H_2	Arcing

This method has the limitation of producing several inconclusive or incorrect fault identifications because it is not always obvious which gas is produced, and the main gas formed might not be one of those used in KGM. Furthermore, CO is not always a reliable predictor of a fault in the cellulose paper cellulose (IEEE, 2019).

2.3.2 Ratio Method



2.3.2.1 Doernenburg Ratio Method (DRM)

Based on IEEE Standard C57.104, Ratio 1, Ratio 2, Ratio 3, and Ratio 4 are the four gas ratios used in this method. It diagnoses various fault conditions such as partial discharge, arcing, and thermal fault in varying degrees of severity using gas ratio ranges.
Table 2 lists the potential diagnostic faults based on gas ratio.

Table 2 Doernenburg Ratio Method in oil (IEEE, 2019).

Suggested Fault Diagnosis	R1 $\frac{CH_4}{H_2}$	R2 $\frac{C_2H_2}{C_2H_4}$	R3 $\frac{C_2H_2}{CH_4}$	R4 $\frac{C_2H_6}{C_2H_2}$
Thermal Decomposition	> 1	< 0.75	< 0.3	> 0.4
Partial Discharge	< 0.1	Not significant	< 0.3	> 0.4
Arcing	0.1 - 1	> 0.75	> 0.3	< 0.4

2.3.2.2 Rogers Ratio Method (RRM)

RRM is built on the IEEE Standard C57.104, and RRM is derived from DRM. RRM is a simple application for diagnosing faults that is dependent on a range of ratios. RRM considers only three ratios, i.e., Ratio 1, Ratio 2, and Ratio 5.
In conjunction with the prescribed diagnostic case, Table 3 displays the specifics for all three gas

ratios. This method is suitable because it links the findings of the failure investigation to the results of the gas analysis in each case.
Certain ratio values in this method, however, do not correspond to the diagnostic code designated to particular faults. When concentration is too high or too low, it will be not possible to detect faults in a significant number of DGA results due to the non-match of any faults, even a fault is clearly visible.

Table 3 Rogers Ratio Method (IEEE, 2019).

Case	R2 $\frac{C_2H_2}{C_2H_4}$	R1 $\frac{CH_4}{H_2}$	R5 $\frac{C_2H_4}{C_2H_6}$	Suggested Fault Diagnosis
0	< 0.1	0.1 - 1	< 1	Normal
1	< 0.1	< 0.1	< 1	Low energy density – PD
2	0.1 - 3	0.1 - 1	> 3	High energy density – Arcing
3	< 0.1	0.1 - 1	1 - 3	Low temperature thermal
4	< 0.1	> 1	1 - 3	Thermal < 700°C
5	< 0.1	> 1	> 3	Thermal > 700°C

2.3.2.3 IEC Ratio Method

This method is similar to the RRM approach. It uses three gas ratios to diagnose faults such as thermal faults in different temperature ranges (300–700°C), electrical faults such as low and high energy cases, and normal aging using IEC 60599 standard shown in Table 4.

2.3.3 Duval Triangle Method

Duval Triangle Method employs three types of gas to determine a different kind of faults which are (IEEE, 2019):

1. CH_4 - to detect low energy or temperature faults.
2. C_2H_4 - to detect high temperature faults.
3. C_2H_2 - to detect very high energy or temperature or arcing faults.

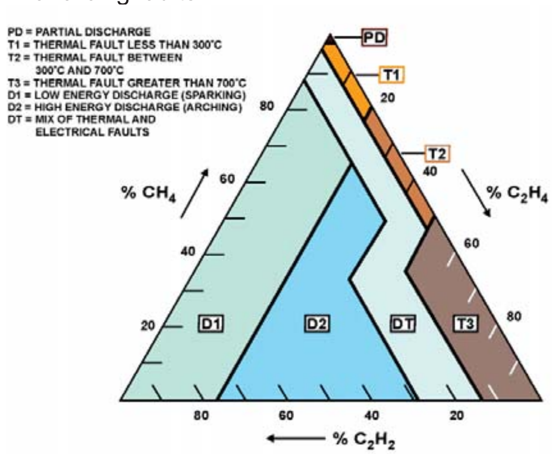


Fig.2 Coordinates and fault zones in Duval Triangle.

As shown in Fig.2, the relative percentages (%) of these three gases are plotted on each side of the triangle. Duval Triangle flowchart, as presented in Fig.6, is to be applied in MATLAB software.
Duval Triangle is a "closed-system" diagnosis methodology that can always produce a result, although sometimes the result may not be 100% correct. It is a simple application and user-friendly, but the disadvantage is, mistakes and incorrect results will easily occur if the handling method is improper (Wannapring et al., 2016).

3. MATLAB IMPLEMENTATION

MATLAB is used in this work to represent results of all methods at one window. 100 samples from previous IEEE reference papers (Ahmed et al., 2013; Akbari et al., 2010; Ayalew et al., 2018; Bakar et al., 2017; Febriyanto & Saha, 2008; Ghoneim et al., 2019; Hmood et al., 2012; Sarma & Kalyani, 2004; Shanker et al., 2018; Shrivastava & Choubey, 2012; Taha et al., 2015; Taha et al., 2015; Vishnu & Kulkarni, 2017; Wannapring et al., 2016) are diagnosed by using both conventional and hybrid methods that generate various characteristics of data by taking concentration value of gases in parts per million (ppm).

3.1 Doernenburg Ratio Method

Fig.3 illustrates a flow chart for the MATLAB program that details all the codes and their respective ranges.
The input ratios are referring to the calculation of the four ratios in Table 2 and exhibit the fault state as an output.

3.2 Rogers Ratio Method

The flowchart of MATLAB program, shown in Fig.4, displays all the diagnostic cases and their respective ranges.
The input gas concentrations were applied as the input to MATLAB program. The ratios calculated based on Table 3 by the program were evaluated to use it as the input.

3.3 IEC Ratio Method

The flowchart of the completed MATLAB program in Fig.5, which shows all the codes, and their ranges will be built based on Table 4.
The input gas concentrations were evaluated to correspond codes and exhibits the fault state as an output.

3.4 Duval Triangle Method

The MATLAB program of this method is built based on the flowchart presented in Fig.6. The flowchart is created by referring to Fig.2 where the relative percentages (%) of three gases are plotted on each side of the triangle.
The percentage of gas concentrations are calculated by dividing the individual gas concentration with total sum of all three gas

concentrations. The results will lead to output fault state.

Table 4 IEC 60599 Ratio code (International Standard, 2014).

	IEC 599	R2 $\frac{C_2H_2}{C_2H_4}$	R1 $\frac{CH_4}{H_2}$	R5 $\frac{C_2H_4}{C_2H_6}$	
	Ratio characteristic gases				
	< 0.1	0	1	0	
	0.1 – 1	1	0	0	
	1 – 3	1	2	1	
	> 3	2	2	2	
Case No.	**Characteristic Fault**				**Typical Example**
0	No fault	0	0	0	Normal aging
1	Partial discharge of low energy density	0 but not significant	1	0	Discharges in gas-filled cavities resulting from incomplete impregnation, or supersaturation or cavitation, or high humidity.
2	Partial discharge of high energy density	1	1	0	As above but leading to tracking or perforation of solid insulation.
3	Discharges of low energy	1 – 2	1	1 – 2	Continuous sparking in oil between bad connections of different potential or to floating potential. Breakdown of oil between solid materials.
4	Discharges of high energy	1	0	2	Discharges with power follow-through. Arcing-breakdown of oil between windings or coils, or between coils to earth. Selector breaking current.
5	Thermal fault of low temperature < 150°C	0	0	1	Local overheating of the core due to concentrations of flux. Increasing hot spot temperatures; varying from small hot spots in the core, overheating of copper due to eddy currents, bad contacts/joints (pyrolytic carbon formation) up to core, and tank circulating currents.
6	Thermal fault of low temperature 150 - 300°C	0	2	0	
7	Thermal fault of medium temperature 300 - 700°C	0	2	1	
8	Thermal fault of high temperature > 700°C	0	2	2	

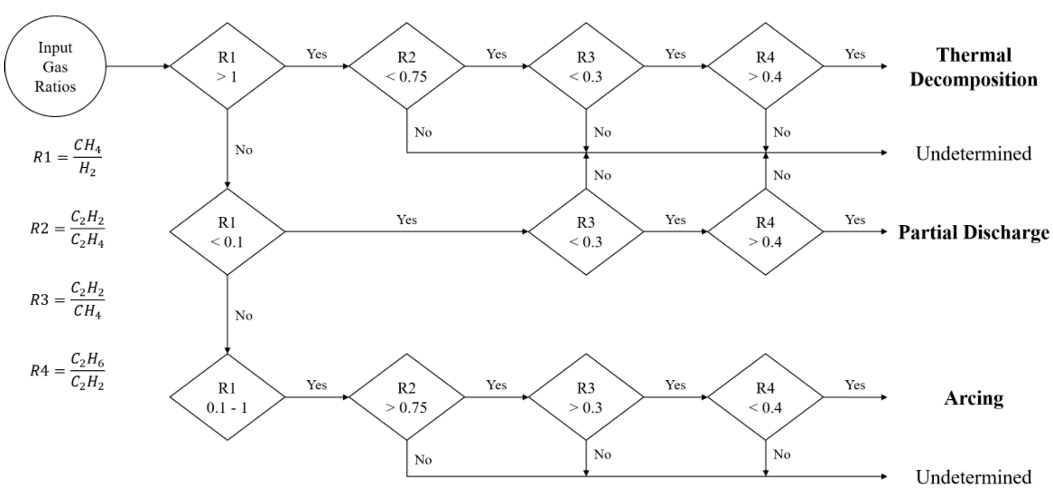


Fig.3 Flowchart of DRM in MATLAB.

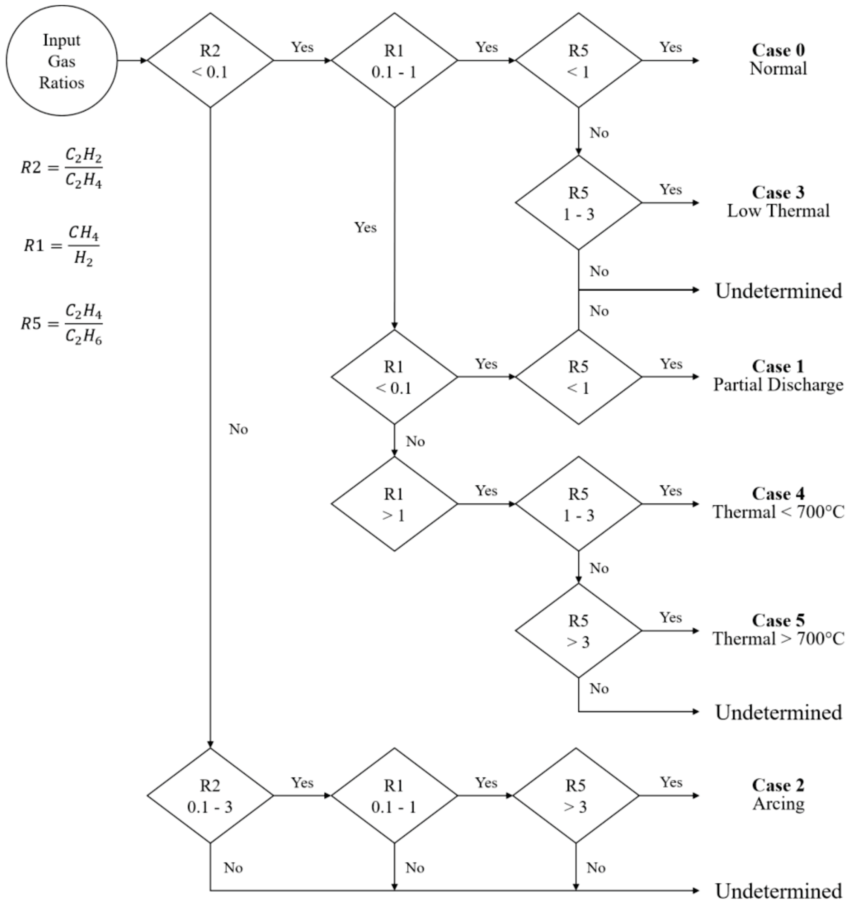


Fig.4 Flowchart of RRM in MATLAB.

4. PROPOSED HYBRID RATIO METHOD

Hybrid method is a fresh new proposal to act as an alternative or rather an additional testing mode by utilizing all the five gas ratios. It is a combining the capabilities of any two out of three ratio methods. Ratio analysis is useful analytical tool for measuring performance of DGA methods. By combining two ratio methods, the evaluation of gas concentrations can be handled with single study. Thus, this study helps lowering time to provide results through automation and reducing complexity.

4.1 Combination Doernenburg and Rogers

Table 5 shows the combination of ratio codes between DRM and RRM. Fig.7 show the flowchart of MATLAB program for this hybrid method. Ratio 3 and Ratio 4 are obtained from DRM ratio codes while Ratio 5 is referred to RRM. Meanwhile, Ratio 1 and Ratio 2 are combinations between DRM and RRM.

Table 5 Combination DRM + RRM ratio code.

Suggested Fault Diagnosis	R1 $\frac{CH_4}{H_2}$	R2 $\frac{C_2H_2}{C_2H_4}$	R3 $\frac{C_2H_2}{CH_4}$	R4 $\frac{C_2H_6}{C_2H_2}$	R5 $\frac{C_2H_4}{C_2H_6}$
Thermal	> 0.1	< 0.75	< 0.3	> 0.4	> 1
Partial Discharge	< 0.1	Not significant	< 0.3	> 0.4	< 1
Arcing	0.1 - 1	0.75 - 3	> 0.3	< 0.4	> 3

4.2 Combination Doernenburg and IEC

The second hybrid method is combination between IEEE and IEC methods. The IEEE method is utilizing DRM. Table 6 shows the ratio codes which is a combination between DRM and IEC ratio method. The flowchart of this hybrid method displays in Fig.8. Ratio 3 and Ratio 4 are obtained from DRM ratio code while Ratio 5 is referred to IEC ratio code. Meanwhile, Ratio 1 and Ratio 2 are combination between DRM and IEC ratio methods.

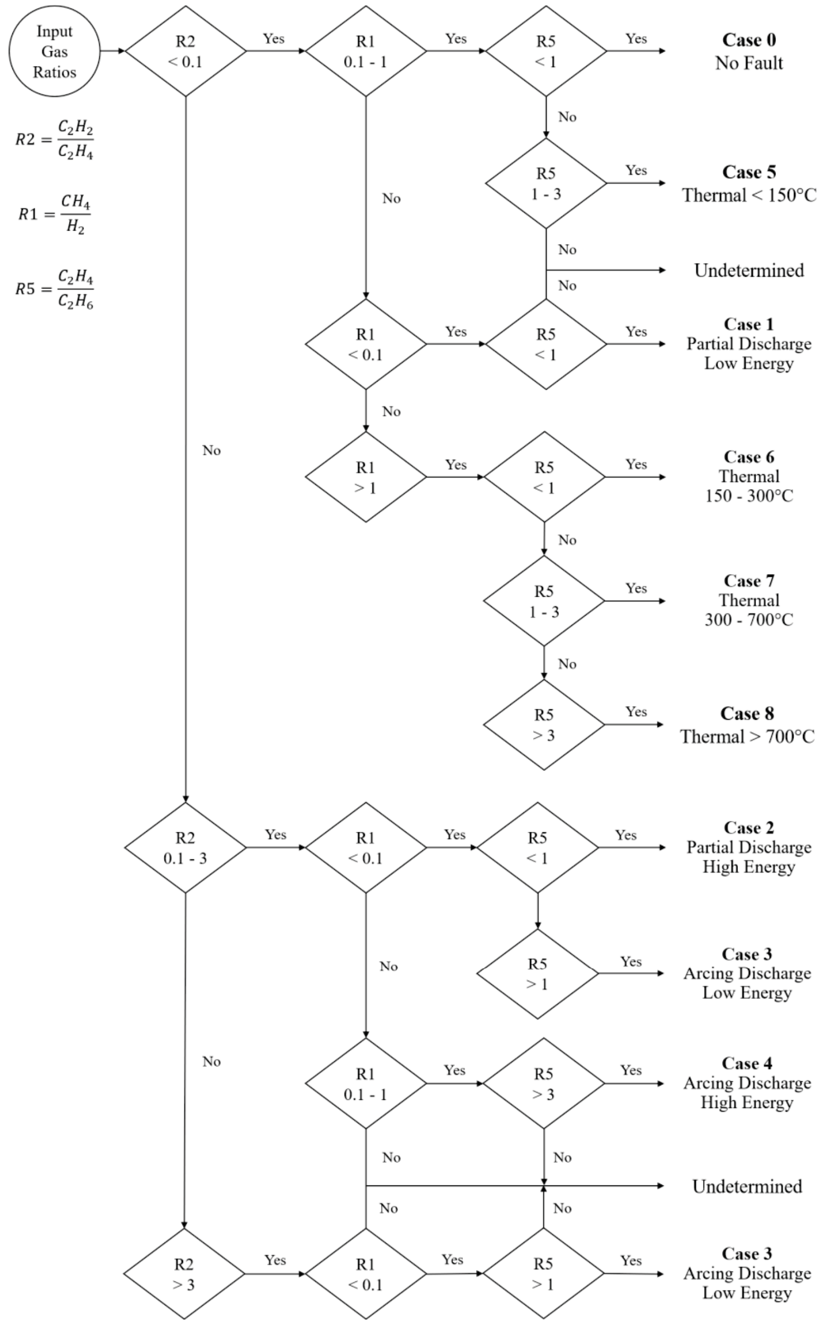


Fig.5 Flowchart of IEC in MATLAB.

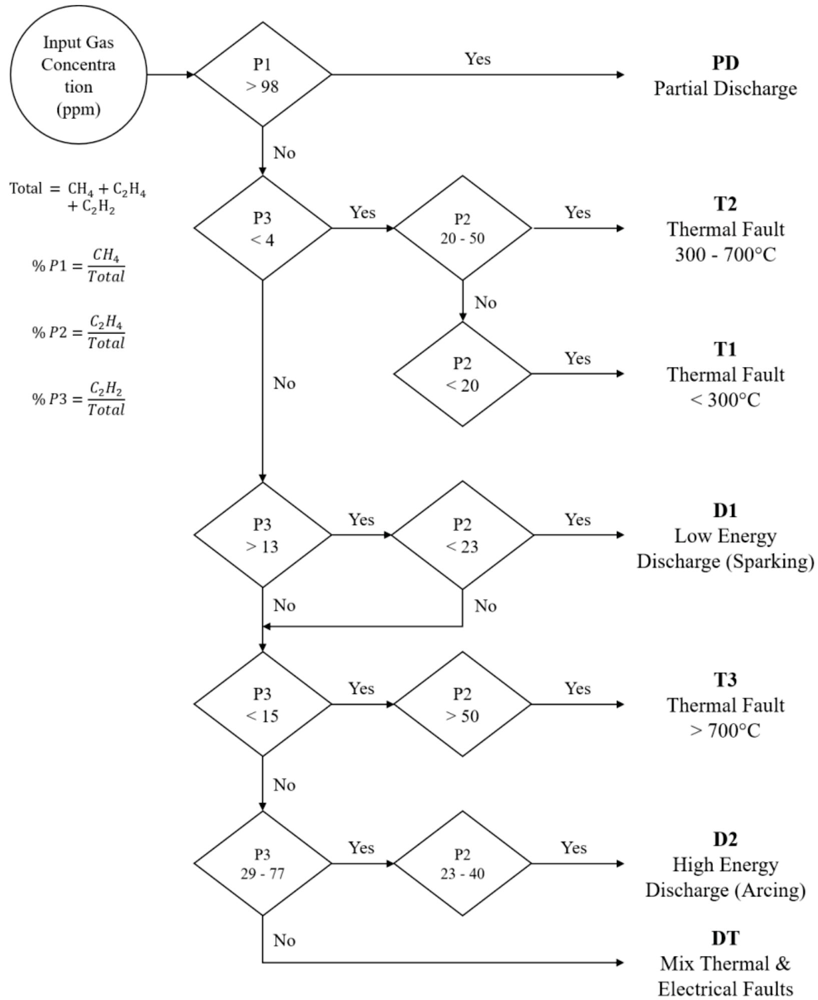


Fig.6 Flowchart of Duval Triangle in MATLAB.

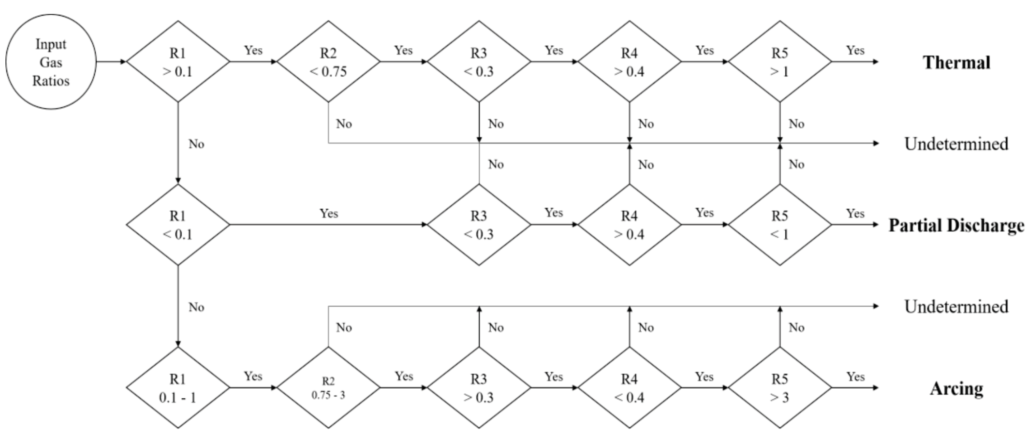


Fig. 7 Flowchart of combination DRM + RRM in MATLAB.

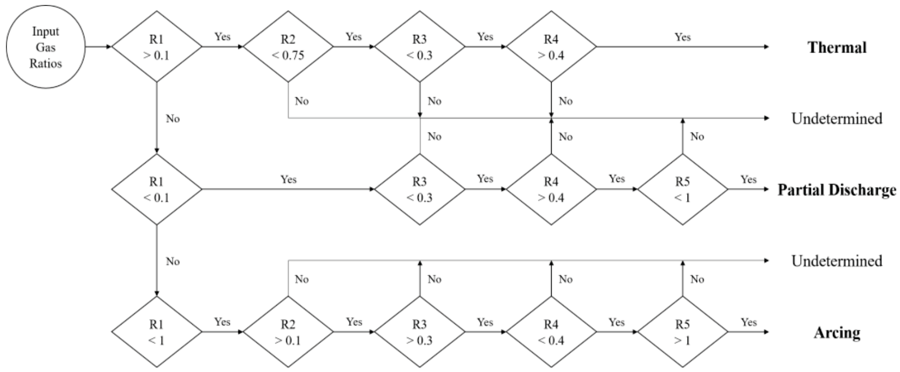


Fig. 8 Flowchart of combination DRM + IEC in MATLAB.

5. DATA ANALYSIS

5.1 Individual Method

KGM has the lowest accuracy of 75% among other four methods. It is due to KGM is focusing on the largest number of dissolved gases concentrations, so it appeared to have different results than the actual. Besides KGM utilizes only four dissolved gases (CO, H_2, C_2H_4, C_2H_2) and other two gases (CH_4, C_2H_6) were not being used, so the diagnosis result becoming inadequate and limited. There are few sample units of CH_4 and C_2H_6 having larger concentration values than the other four gases.

RRM has also produced a quite low accuracy of 79%. RRM's inability to detect faults is when concentration value reached too high or too low, even though the faults are visible if using other methods. There are also a few sample unit's ratio values that do not correspond to diagnostic codes.

As there are many studies recognized Duval Triangle is one of reliable method with 80% accuracy, but it is still categorized as below satisfactory level. When mineral oil is decomposed, gas molecules will release H_2, CH_4, C_2H_6, C_2H_4, and C_2H_2, as such it is inappropriate for Duval Triangle to use only three dissolved gases and neglect the remaining two gases.

Fig.9 shows that DRM and IEC are the best methods with an accuracy of 94% each. Both DRM and IEC are utilizing all the five dissolved gases and ratio value complies with given diagnostic fault codes.

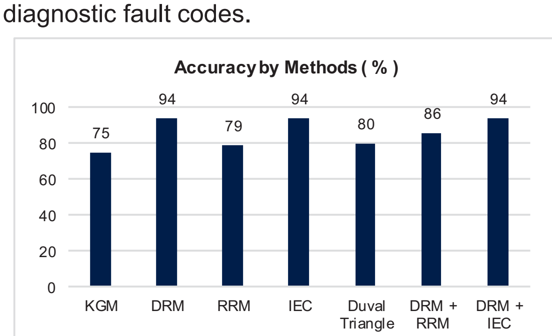


Fig.9 Accuracy of DGA methods for overall.

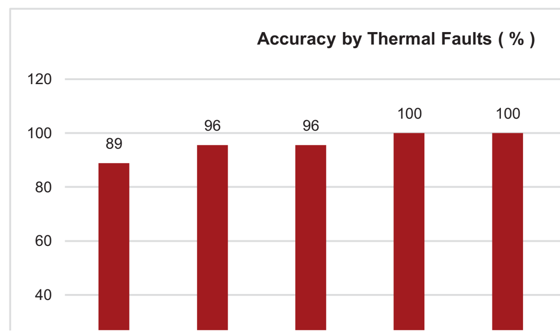


Fig.10 Accuracy for Thermal fault.

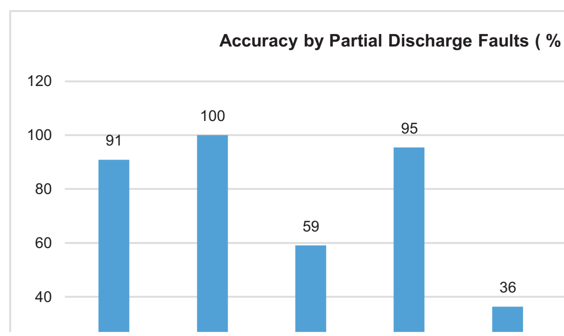


Fig.11 Accuracy Partial Discharge fault.

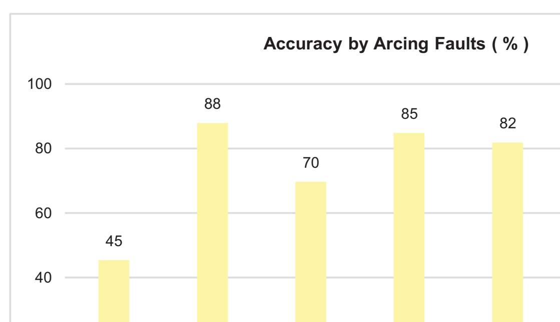


Fig.12 Accuracy for Arcing fault.

DRM, it is using more ratios and helps to provide significant information for fault diagnosis analysis and determine efficient the insulation oil is operating.

RRM and IEC indeed use similar gas ratios, however, the difference is that IEC has bigger fault case number of 8 compared to RRM which has only 5 fault cases. Due to IEC uses more fault case numbers and characteristics, dissolved gases can be studied more thoroughly, hence the risk of misinterpretation is mitigated.

Thermal faults produce degradation gases CH_4, C_2H_6, and C_2H_4 inside the mineral oil. To detect the thermal faults during the early stage as shown in Fig.10, IEC and Duval Triangle are the best to be applied as a perfect accuracy of 100% is obtained by both methods. DRM and RRM having similar 96% accuracy, KGM on the other hand has the lowest accuracy of 89% only.

When H_2 is at a very high-value concentration, partial discharge tends to happen inside the mineral oils. Fig.11 shows that DRM gives 100% accurate interpretation of partial discharge data follows by IEC method with 95% accuracy. Unfortunately, Duval Triangle cannot be applied in partial discharge fault analysis although this method is the best for thermal fault detection.

Arcing faults happens when the amount of C_2H_2 is too high. DRM is the best diagnostic method for arcing fault detection with 88% accuracy as shown in Fig.12. IEC also gives a good satisfactory result with an accuracy of 85%. Meanwhile, KGM is the lowest accuracy recorded at 45% only, hence it is not suitable to be applied for arcing fault interpretation.

5.2 **Hybrid Method**

As shown in Fig.9, combination of DRM and RRM shows improvement as it increases the performances from initial individual RRM of 79% to current of 86%. It shows that DRM plays an important role to improve weakness of RRM.

When DRM combined with IEC, they recorded a steady 94% accuracy which is similar to the result obtained during individual method. Thus, it does not matter which method is to be used to study dissolved gas in insulation oil.

From Fig.10, both individual DRM and RRM have a good 96% accuracy of thermal fault prediction before it suddenly drops to 93% in hybrid method. For thermal fault, IEC as individual is the best method to be applied with an accuracy of 100%. The result tends to slightly drop to 98% when it combined with DRM, because DRM as individual has only 96%.

Reference to partial discharge fault in Fig.11 and as individual, IEC has a good accuracy of 95% while DRM recorded a perfect 100%. Fortunately, when both are combined to perform hybrid method, they remain at 100% and becoming ideal method for this application.

For arcing fault, the result of 67% accuracy recorded for DRM and RRM combination, and 85% for DRM and IEC combination in hybrid method, could be considered as not meeting to satisfactory level. Hence from Fig.12, it is clear that combination of DGA methods could not give a clear exact incipient fault to a very accurate result.

6. CONCLUSION

By using MATLAB software program, the accuracy and reliability of five conventional DGA methods plus another two proposed hybrid methods can be determined

For the overall accuracy of DGA methods, DRM and IEC as an individual are the ideal method to diagnose incipient faults. As for hybrid method, combination between DRM and IEC is still the best option as they constantly give the highest accuracy level of 94%.

Based on accuracy to diagnose thermal fault, IEC, and Duval Triangle as an individual has both delivered a good accuracy. Diagnosis using hybrid method, combination between DRM and IEC has produced 98% accuracy which is still acceptable. As such, individual method is the best option to detect thermal fault.

Looking at partial discharge fault diagnosing, both hybrid methods together with individual DRM, show the best performance with a perfect 100% accuracy.

Precautions for the worst-case scenario such as arcing, a regular inspection shall be carried out to avoid serious problem in the future. Among all the methods, DRM shows a promising result as the best option for arcing result detection.

It concludes that with the additional findings of potential faults as above, immediate remedial action shall be taken when insulating medium starts to deteriorate and ultimately avoid transformer failure.

Table 6 Comparison diagnosis methods.

Method	Overall	Thermal	Partial Discharge	Arcing
KGM				
DRM	✓		✓	✓
RRM				
IEC	✓	✓		
Duval Triangle		✓		
DRM + RRM			✓	
DRM + IEC	✓		✓	

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APPENDIX

S/N	CO	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	Actual	KGM	DRM	RRM	IEC	Duval	DRM + RRM	DRM + IEC
1		109	19	5	12	59	AR	AR	AR	UD	AR	AR	UD	AR
2		179	29	10	17	33	AR	AR	AR	UD	AR	AR	UD	AR
3		41	16	19	58	106	AR	AR	AR	AR	AR	AR	AR	AR
4		37	11.8	15.5	43.6	83.3	AR	AR	AR	UD	AR	AR	UD	AR
5		650	53	35	20	0.1	PD	PD	PD	PD	PD	TH	PD	PD
6		9	38	93	8	0.00001	TH	UD	TH	UD	TH	TH	UD	TH
7		27	136	46.9	131	0.1	TH	UD	TH	TH	TH	TH	TH	TH
8		769	999	234	1599	31	TH	TH	TH	TH	TH	TH	TH	TH
9		36	245	144	332	0.01	TH	TH	TH	TH	TH	TH	TH	TH
10		150	110	90	280	50	AR	TH	UD	AR	AR	TH	UD	UD
11		24	13	5	43	319	AR	AR	AR	UD	AR	AR	UD	AR
12		266	584	328	862	1	TH	TH	TH	TH	TH	TH	TH	TH
13		160	10	3	1	1	AR	PD	PD	UD	PD	DT	PD	PD
14		80	619	326	2480	0	TH	TH	TH	TH	TH	TH	TH	TH
15		231	3997	1726	5584	0	TH	TH	TH	TH	TH	TH	TH	TH
16		127	24	0	32	81	AR	AR	AR	AR	AR	AR	AR	AR
17		9474	4066	353	6552	12997	AR	AR	AR	AR	AR	AR	AR	AR
18		507	1053	297	1440	17	TH	TH	TH	TH	TH	TH	TH	TH
19		416	695	74	867	0	TH	TH	TH	TH	TH	TH	TH	TH
20		441	207	43	224	261	AR	AR	AR	AR	AR	AR	AR	AR
21		16	87	75	395	30	TH	TH	UD	TH	TH	TH	UD	UD
22		212	38	15	47	78	AR	AR	AR	AR	AR	AR	AR	AR
23		199	770	217	1508	72	TH	TH	TH	TH	TH	TH	TH	TH
24		425	17424	7299	37043	158	TH	TH	TH	TH	TH	TH	TH	TH
25		244	754	172	1281	27	TH	TH	TH	TH	TH	TH	TH	TH
26		117	167	48	481	7	TH	TH	TH	TH	TH	TH	TH	TH
27		137	369	144	1242	16	TH	TH	TH	TH	TH	TH	TH	TH
28		1249	370	56	606	1371	AR	AR	AR	AR	AR	AR	AR	AR
29		33	79	30	215	5	TH	TH	TH	TH	TH	TH	TH	TH
30		60	144	67	449	9	TH	TH	TH	TH	TH	TH	TH	TH
31		2004	9739	2750	5113	0	TH	UD	TH	TH	TH	TH	TH	TH
32		127	107	11	154	224	AR	AR	AR	AR	AR	AR	AR	AR
33		8653	817	208	3	2	PD	PD	PD	UD	PD	PD	PD	PD
34		44	250	116	1989	0	TH	TH	TH	TH	TH	TH	TH	TH
35	360	269	1081	347	1725	25	TH	TH	TH	TH	TH	TH	TH	TH
36	334	206	42	16	82	221	AR	TH	AR	AR	AR	AR	AR	AR
37	224	56	286	96	928	7	TH	TH	TH	TH	TH	TH	TH	TH

S/N	CO	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	Actual	KGM	DRM	RRM	IEC	Duval	DRM + RRM	DRM + IEC
38	198	78	161	86	353	10	TH	TH	TH	TH	TH	TH	TH	TH
39	400	50	100	51	305	9	TH	TH	TH	TH	TH	TH	TH	TH
40	400	172	335	171	812	37.8	TH	TH	TH	TH	TH	TH	TH	TH
41	470	27	90	42	63	0.2	TH	TH	TH	TH	TH	TH	TH	TH
42	317	32.4	5.5	1.4	12.6	13.2	AR	TH	AR	AR	AR	DT	AR	AR
43	370	74	142.2	41.8	324.9	5.3	AR	TH	TH	TH	TH	TH	TH	TH
44	350	76	140	40.8	317	5.2	TH	TH	TH	TH	TH	TH	TH	TH
45	380	30.4	117	44.2	138	0.1	TH	TH	TH	TH	TH	TH	TH	TH
46	350	30.8	149	47.9	146	0.1	TH	TH	TH	TH	TH	TH	TH	TH
47	380	1607	615	80	916	1294	AR	AR	AR	AR	AR	AR	AR	AR
48	404	173	334	172	812.5	37.7	TH	TH	TH	TH	TH	TH	TH	TH
49	777	220	340	42	480	14	TH	TH	TH	TH	TH	TH	TH	TH
50	544	170	320	53	520	3.2	TH	TH	TH	TH	TH	TH	TH	TH
51	487	565	53	34	47	0.1	AR	PD	PD	UD	UD	TH	UD	UD
52	225	200	48	14	117	131	AR	TH	AR	AR	AR	AR	AR	AR
53	243	980	73	58	12	0.1	PD	PD	PD	PD	PD	TH	PD	PD
54	404	300	490	180	360	5	TH	UD	TH	TH	TH	TH	TH	TH
55	252	200	700	250	740	1	TH	TH	TH	TH	TH	TH	TH	TH
56	746	18	35	2	110	0.1	TH	TH	TH	TH	TH	TH	TH	TH
57	580	360	492	54	305	1	TH	TH	TH	TH	TH	TH	TH	TH
58	26	86	187	136	363	0.1	TH	TH	TH	TH	TH	TH	TH	TH
59	343	10	24	372	24	0.1	TH	UD	TH	UD	TH	TH	UD	TH
60	219	106	24	4	28	37	AR	TH	AR	AR	AR	AR	AR	AR
61	252	180.9	0.5	0.234	0.18	0.1	PD	TH	PD	UD	PD	DT	PD	PD
62	383	16	25	19	39	0.1	TH	TH	TH	TH	TH	TH	TH	TH
63	480	30	5	10	13	0.1	TH	TH	UD	TH	TH	TH	TH	TH
64	697	645	86	13	110	317	AR	TH	AR	AR	AR	AR	AR	AR
65	605	385	60	8	53	159	AR	TH	AR	UD	UD	AR	UD	AR
66	396	595	80	9	89	244	AR	PD	AR	AR	AR	AR	AR	AR
67	350	1770	3630	1070	8480	78	TH	TH	TH	TH	TH	TH	TH	TH
68	225	201	48	14	116	130	AR	TH	AR	AR	AR	AR	AR	AR
69	198	293.5	50	14	116.5	130	AR	PD	AR	AR	AR	AR	AR	AR
70	243	128	106	11.5	153	223	AR	TH	AR	AR	AR	AR	AR	AR
71	250	33	5.4	1.5	12.9	13.6	AR	TH	AR	AR	AR	DT	AR	AR
72	211	469	147	12.5	265	520	AR	AR	AR	AR	AR	AR	AR	AR
73	219	49	12	0.3	4	4.8	AR	TH	AR	AR	AR	AR	AR	AR
74	365	14	237	92	470	0.001	TH	TH	TH	TH	TH	TH	TH	TH
75	480	172	336.5	172.5	821	37	TH	TH	TH	TH	TH	TH	TH	TH
76	697	162.5	224	45.5	497	12.5	TH	TH	TH	TH	TH	TH	TH	TH

S/N	CO	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	Actual	KGM	DRM	RRM	IEC	Duval	DRM + RRM	DRM + IEC
77	389	160	223	45	495	11	TH	TH	TH	TH	TH	TH	TH	TH
78	523	29	26.3	1.8	29	82.4	AR	TH	AR	AR	AR	AR	AR	AR
79	4753	200.8	59.45	41	40.48	150.8	AR	TH	AR	UD	UD	AR	UD	UD
80	71	7525	1236	281	2460	10414	AR	AR	AR	UD	AR	AR	UD	AR
81	688	1667	146	55	1	0	PD	PD	PD	PD	PD	PD	PD	PD
82	291	432	184	20	259	421	AR	AR	AR	AR	AR	AR	AR	AR
83	816	5	63	18	23	1	TH	TH	TH	TH	TH	TH	TH	TH
84	313	32930	2397	157	0	0	PD	PD	PD	UD	UD	PD	PD	PD
85	56	37800	1740	249	8	8	PD	PD	PD	UD	PD	PD	PD	PD
86		2587.2	112.25	4.704	1.4	0	PD	PD	PD	PD	PD	PD	PD	PD
87		180.85	0.574	0.234	0.188	0.0001	PD	PD	PD	PD	PD	TH	PD	PD
88		106	4	2	1	0.0001	PD	PD	PD	PD	PD	TH	PD	PD
89		109	4	11	9	0.0001	PD	PD	PD	PD	PD	TH	PD	PD
90		134	13	267	0.0001	0.0001	PD	UD	PD	UD	PD	PD	PD	PD
91		40280	1069	1060	1	1	PD	PD	PD	UD	PD	PD	PD	PD
92		5.39	0.42	0.05	0.03	0	PD	PD	PD	PD	PD	TH	PD	PD
93		29.99	1.86	0.74	0.52	0.06	PD	PD	PD	UD	PD	TH	PD	PD
94		30.99	2.86	0.64	0.62	0.07	PD	PD	PD	UD	PD	TH	PD	PD
95		5.78	0.55	0.15	0.07	0.01	PD	PD	PD	UD	PD	TH	PD	PD
96		31.99	2.11	0.66	0.56	0.05	PD	PD	PD	PD	PD	TH	PD	PD
97	556	2031	149	20	3	0	PD	PD	PD	PD	PD	PD	PD	PD
98		260	3	18	2	0	PD	PD	PD	PD	PD	TH	PD	PD
99		586	19	77	6	0	PD	PD	PD	PD	PD	TH	PD	PD
100		574	4	27	3	0	PD	PD	PD	PD	PD	TH	PD	PD