Diagnosis of Power Transformer Depending on Dissolved Gas Analysis

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Dissolved Gas Analysis

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GUI	Graphic User Interface
DGA	Dissolved Gas Analysis
TDG	Total Dissolved Gas
TCG	Total Combustible Gases
GBA	Gas Blanket Analysis
H_2	Hydrogen
N_2	Nitrogen
O_2	Oxygen
H_2O	Water
CO	Carbon Monoxide
CO_2	Carbon Dioxide
C_2H_2	Acetylene
CH_4	Methane
C_2H_6	Ethane
C_2H_4	Ethylene

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Chapter 5

GAS INTERPRETATION TECHNIQUES

Overview:

This chapter mainly describes about block diagram of DGA combine five methods and also it deals with one of the interpretation technique - Key gas method. And also deals with key gas method code representation by MATLAB GUI program.

5.1 Block Diagram of DGA Combine Method
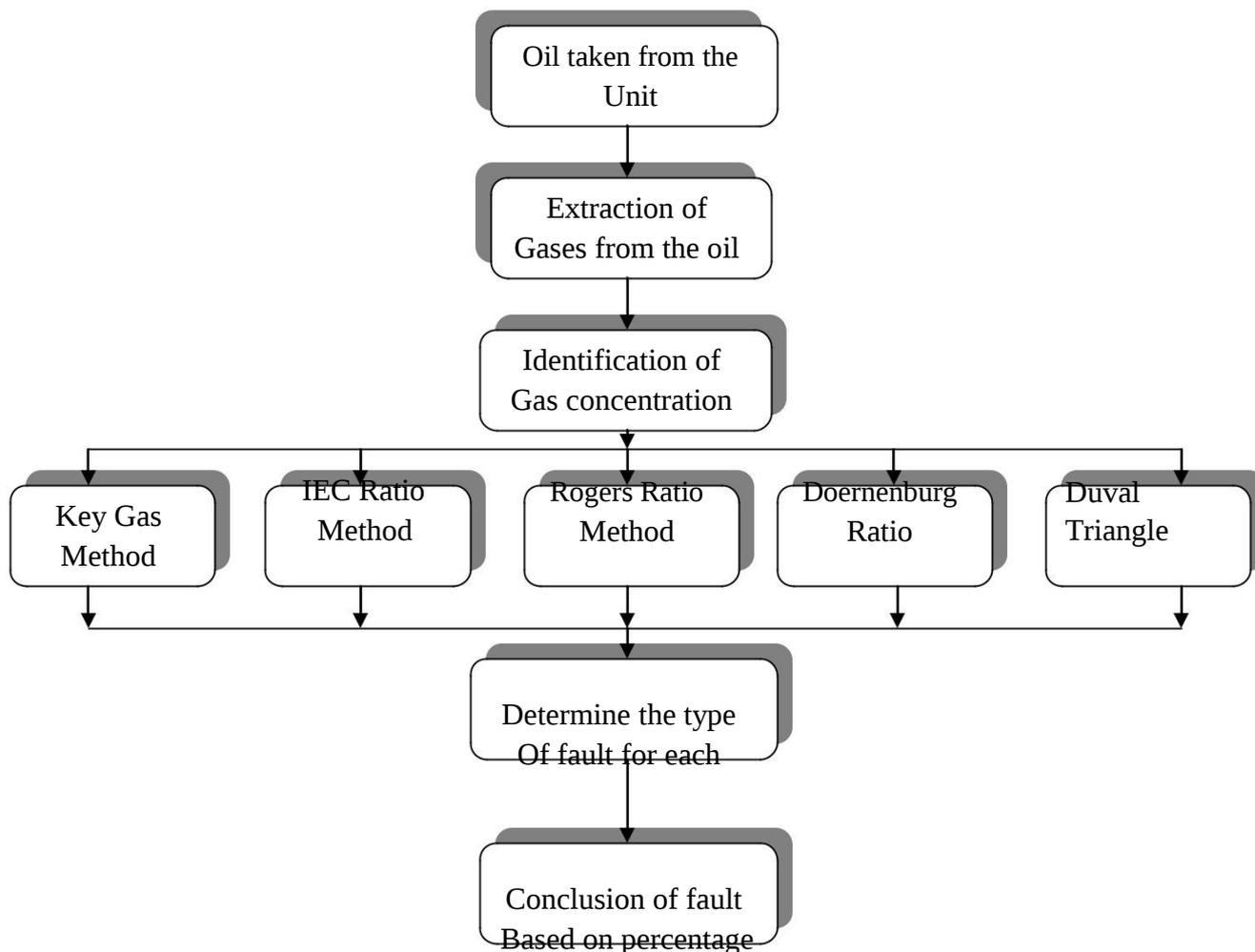
Figure 5.1: Block diagram of Combined Dissolved Gas Analysis (DGA) Method

Figure 5.1 explains the fault experienced by all traditional methods (key gas, IEC, Doernenburg Ratio, Rogers Ratio, and Duval's Triangle Method). After extract dissolved gases from the mineral oil, it is carried out to find the gas concentrations. For find volume of dissolved gases several methods were proposed but among that Direct Injection Technique and The head Space Method are most accuracy methods and it gives directly volume of dissolved gases by injecting mineral oil [19]. By giving input as a gas concentrations in ppm (parts per million) for each diagnostic method, it gives incipient fault type. The next step is compare all incipient fault types by each method and finally conclusion gives final fault of unit (mineral oil) based on percentage given by each method.

The main reason for going combine five methods is "none of the single method is giving all type of faults i.e. key gas method gives only thermal faults in oil and cellulose, discharge of low energy and high energy faults. In case of ratio methods gives high thermal, partial

Discharge and arcing but not giving combination of thermal and electrical faults. In case of Duval's triangle method gives almost all possible faults except faults temperature $<150^0$c, if these low temperature faults are not corrected may be it leads to high temperature faults in future and perhaps increase to arcing and these causes high damage to transformer. So if combine all these five methods, it detects all possible faults like low and high thermal faults, partial discharge, arcing and combination of thermal and electrical faults". Normally by taking same sample unit different diagnosis methods gives different fault conditions, but in case of this combine DGA method gives result as only one common indication of fault by considering all individual methods faults. So it is giving prior intimation for occurring faults, hence by taking remedies for occurring incipient faults life period of power transformer is increased and failure percentage of transformer also decreased.

5.2 Key Gas Method

The key gas method is mainly depends on the quantity of fault gases release in mineral oil when fault occur. Figure 5.2 to Figure 5.5 indicates the key gases and their relative proportions for four fault types and Table 1 shows the limitations of key gas method for each key gas [1]. Generally the thermal decomposition of oil produced more than 60% of ethylene (C_2H_2) and thermal decomposition of cellulose produce key gas carbon monoxide (CO) is 90%. In case of corona in oil mainly produce large amount principal gas hydrogen nearly 80% and due to arcing key gas acetylene produced 30% with trace quantity of hydrogen [11].

5.2.1 Thermal Faults

i. ***Thermal Faults in Oil***

❖ If thermal faults occurred in mineral oil, mainly methane and ethylene gases are released and very less quantity of ethane and hydrogen gases also produced [16].

❖ If the fault is severe or involves electrical contacts, small quantity of acetylene gas in ppm produced.

❖ The main Key gas exists when thermal faults occurred is ethylene (C_2H_4).
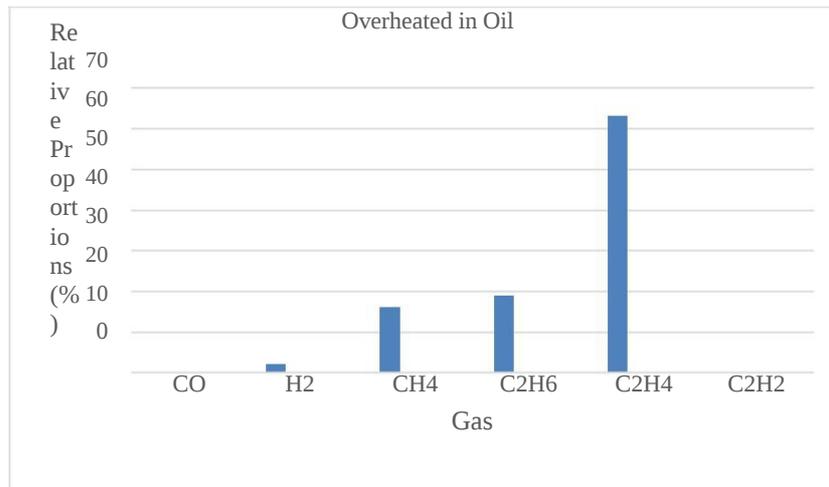
Figure 5.2 Approximate percentage (%) of gases found during

thermal faults in oil inside the Transformer

ii. ***Thermal Faults in Cellulose***

- It produced large quantity of carbon monoxide and carbon dioxide

- The main key gas is carbon monoxide (CO).

Figure 5.3 shows approximate relative proportions (%) for each fault gas. In this case CO Produce more than 90%.
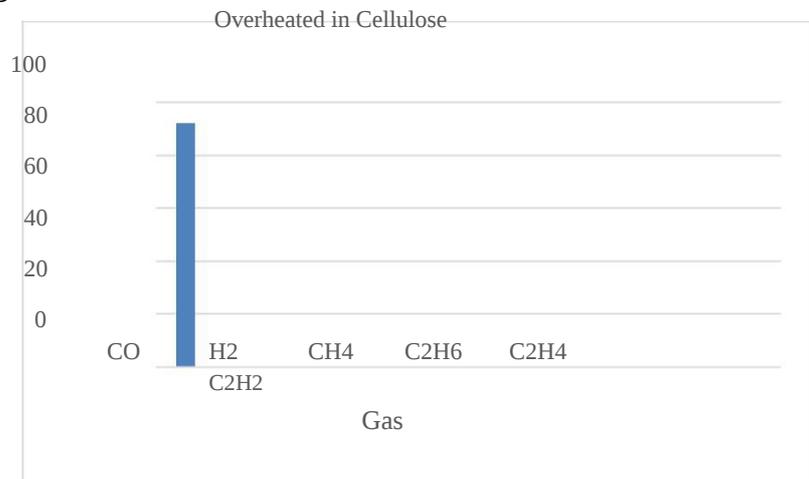
Figure 5.3: Approximate percentage (%) of gases found during

thermal faults in Cellulose inside the Transformer.

5.2.2 Electrical Faults

i. ***Corona***

- Due to partial discharge (or) corona in oil, mainly methane and hydrogen gases are produced with less quantity of ethylene and ethane gases.

☐ The main key gas produced due to corona in oil is hydrogen (H_2).

Figure 5.4 shows approximate relative proportions (%) for each fault gas in corona.
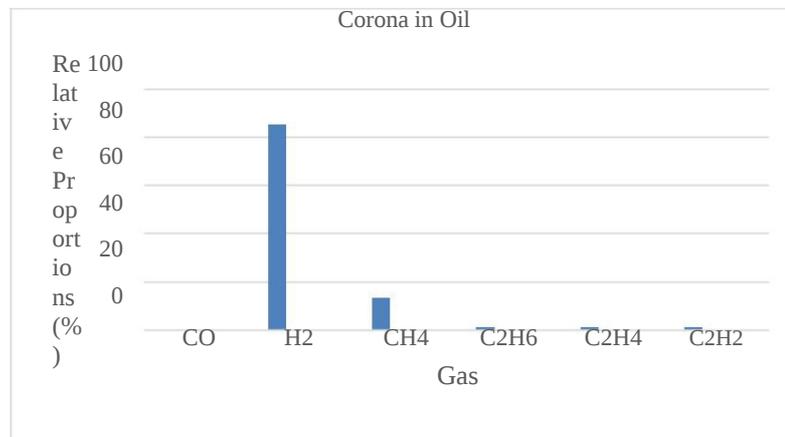
5.4: Approximate percentage (%) of gases found During Corona in oil inside the Transformer

iii. ***Arcing***

✓ Due to arcing (or) high energy discharge in oil produced mainly acetylene and hydrogen gases.

✓ If arcing exists in cellulose releases carbon oxides

✓ The main key gas due to arcing is acetylene (C_2H_2).

Figure 5.5 shows approximate relative proportions (%) for each fault gas in arcing.
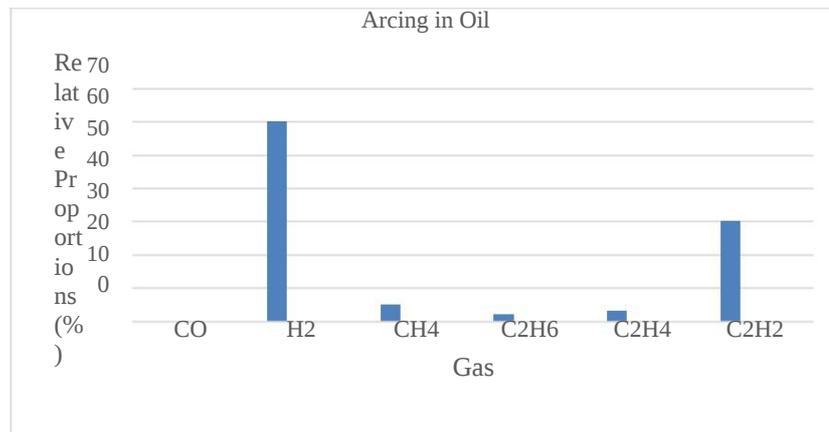
Figure 5.5: Approximate percentage (%) of gases found during Arcing in oil inside the Transformer

Figure 5.6 indicates the flow chart representation of key gas method to MATLAB GUI program. Instead of taking ratios, here taking only principle gases concentration

In relative percentages to diagnosis the faults [18]. Before going to check fault status in key gas method, it will check gas concentrations values limitations in Table 5.2
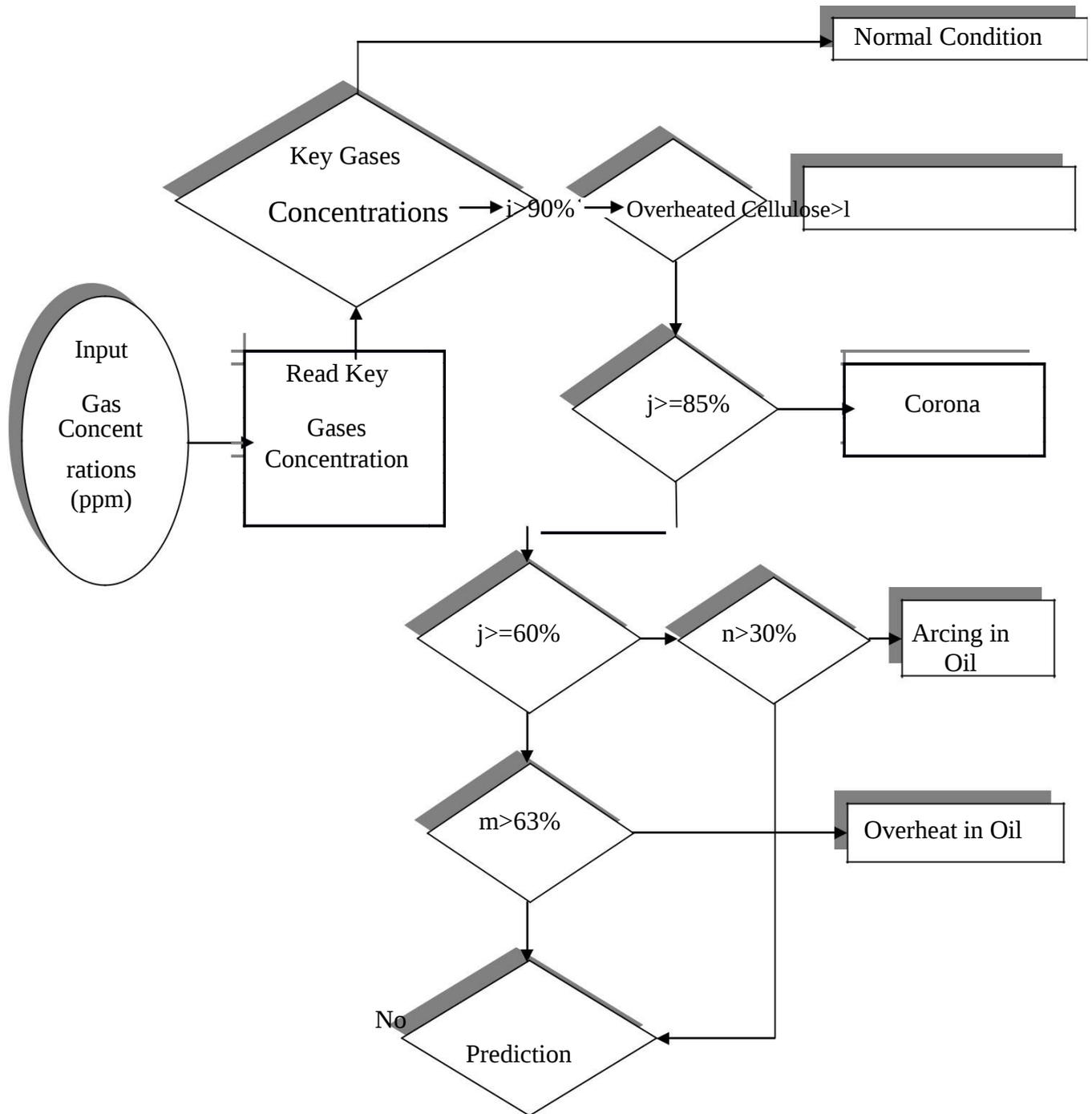
Figure 5.6: Flow Chart of Identification of gases present in Transformer oil using Key Gas Method

5.3 Key Gas Method Software implementation to MATLAB GUI

MATLAB Graphical User Interface (GUI) is a user friendly tool in MATLAB; it gives visual display for entire key Gas method at one window. Take the nine gases concentrations as input in ppm and read each key gas concentration for checking fault status. If key gas concentrations values more than shown in Table 5.2, it represents fault exist otherwise shows normal condition. Figure 5.6 represents total steps involved to develop MATLAB GUI software.
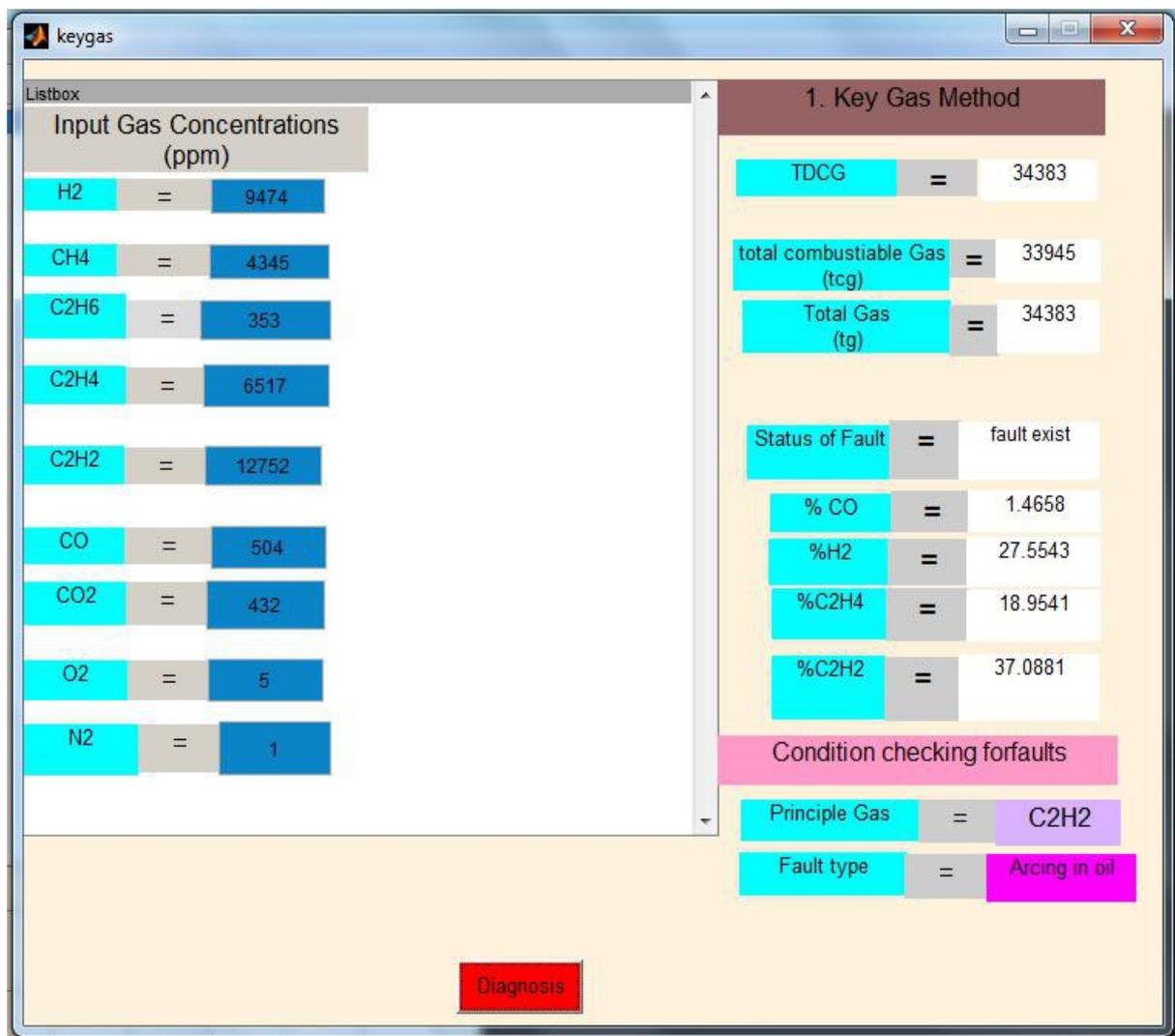
Figure 5.7: Result window of Key Gas Method using MATLAB GUI

5.4 Result and Discussions

Figure 5.7 indicates the GUI result for key gas method and for instance, gas concentrations taken as input (ppm) shown in Table 5.1

TABLE 5.1 INPUT GASES AND CONCENTRATIONS IN PPM

Input gas	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO	CO_2	O_2	N_2
Concentration (ppm)	9474	4345	353	6517	12752	504	432	5	1

TDCG gives summation of total dissolved combustible gases and TCG gives summation of total gas concentration without noncombustible gas CO_2. The GUI result in Figure 5.7 given status of the fault as "fault exist", it means one of the key gas concentrations volumes is more than Table 5.2.

TABLE 5.2: LIMITATIONS OF KEY GAS METHOD [16]

Key Gas	Gas Concentration (ppm)
H_2	150
CO	500
C_2H_4	20
C_2H_2	15

Hence this method goes further steps for diagnosis of faults type and finally it given fault type as "Arcing in Oil" and principal gas C_2H_2 as 37.088%. It shows the given sample unit produced acetylene gas more than 30% due to arcing in oil.

Chapter 6

RATIO METHODS TO INTERPRETATION OF DGA

Overview:

This chapter mainly deals with DGA interpretation techniques like Roger's Ratio, IEC Ratio and Dornenburg's Ratio methods and their codes representation for each method and flow chart representation for development of MATLAB GUI program for each diagnostic technique.

6.1 Rogers Ratio method

6.1.1 Introduction

Rogers ratio method diagnosis the faults by taking the ranges of gas ratios in mineral oil; it takes four gas ratios are C_2H_2/C_2H_4, C_2H_6/CH_4, C_2H_4/C_2H_6 and CH_4/H_2. By using these four gas ratios, it diagnosis the faults like normal ageing, winding circulating currents, electrical faults, low energy discharge faults and thermal faults in various ranges(150^0c-700^0c) [9]. The main advantage of gas ratio analysis is "***it is independent on volume of oil involved and it is only depends on ratios of gases involved***" [1].

6.1.2 Diagnosis Codes Representation

Table 6.1 indicates gas ratios uses in Roger's ratio method and their ratio code representation used in MATLAB GUI program.

TABLE 6.1: ROGERS RATIO METHOD RATIO CODE REPRESENTATION [9]

SL.NO	Gas Ratios	Ratio Codes
1	CH_4/H_2	i
2	C_2H_6/CH_4	j
3	C_2H_4/C_2H_6	k
4	C_2H_2/C_2H_4	l

By using four gas ratios in Table 6.1, as IEEE Standard C57.104-1991 gives more information to find exact faults [9]. Table 6.2 indicates the gas ratio codes for Rogers's ratio method and it indicates type of faults occurred. Table 6.2 shows gas ratios range and codes in 0-5, codes used in Table 6.2 is only the software implementation purpose of Rogers ratio method and by using gas ratios range in Table 6.2, different faults conditions are developed. If any fault gases ratio range is beyond ratios shown in Table 6.2, this method is unable to find Incipient faults status and shows Rogers ratio method is not valid.

TABLE 6.2: ROGERS RATIO CODE REPRESENTATION

Ratio Code	Range	Code
$i\ (CH_4/H_2)$	<=0.1	5
	0.1-1.0	0
	>=1.0,<3.0	1
	>=3.0	2
$j\ (C_2H_6/CH_4)$	<1.0	0
	>=1.0	1
$k\ (C_2H_4/C_2H_6)$	<=1.0	0
	>=1.0,<3.0	1
	>=3.0	2
$l(C_2H_2/C_2H_4)$	<0.5	0
	>=0.5,3.0	1
	>=3.0	2

By using Table 6.2 gas ratio ranges, developed 12 cases of possible diagnosis incipient faults
In mineral oil. Table 6.3 indicates total possible cases of faults diagnosis by Rogers's ratio
Method and their gas ratio range and codes representation for each case.

TABLE 6.3: TOTAL POSSIBLE DIAGNOSIS FAULTS FOR ROGERS RATIO METHOD

SL.NO	$i\ (CH_4/H_2)$	$j(C_2H_6/CH_4)$	$k(C_2H_4/C_2H_6)$	$l(C_2H_2/C_2H_4)$	Diagnosis
1	0(>0.1,<1.0)	0(<1.0)	0(<1.0)	0(<0.5)	Normal deterioration
2	5(<=0.1)	0	0	0	Partial discharge
3	1-2	0	0	0	Slight overheating(<150^0c)
4	1-2	1(>=1.0)	0	0	Overheating(150^0c-200^0c)
5	0	1	0	0	Overheating(200^0c-300^0c)
6	0	0	1	0	General conductor over heating
7	1	0	1	0	Winding circulating currents
8	1	0	2	0	Core & circulating currents (300^0c-700^0c)
9	0	0	0	1	Flash over without power follow through
10	0	0	1-2	1-2	Arc with power follow through
11	0	0	2	2	Continuous sparking to floating potential
12	5	0	0	1-2	Partial discharge with tracking

6.1.3 Rogers Ratio Method Software implementation to MATLAB GUI

Hence by using Table 6.3 developed software to MATLAB GUI program, showing all codes representation and its ranges at one window. Hence by implementing this method in MATLAB GUI can diagnosis the incipient faults. Figure 6.1 shows MATLAB GUI result for Rogers's ratio method. GUI result gives all corresponding gas ratios range and their code and status of the mineral oil i.e. whether it is faulty or not and finally it gives incipient fault type at one window by using ratios ranges.
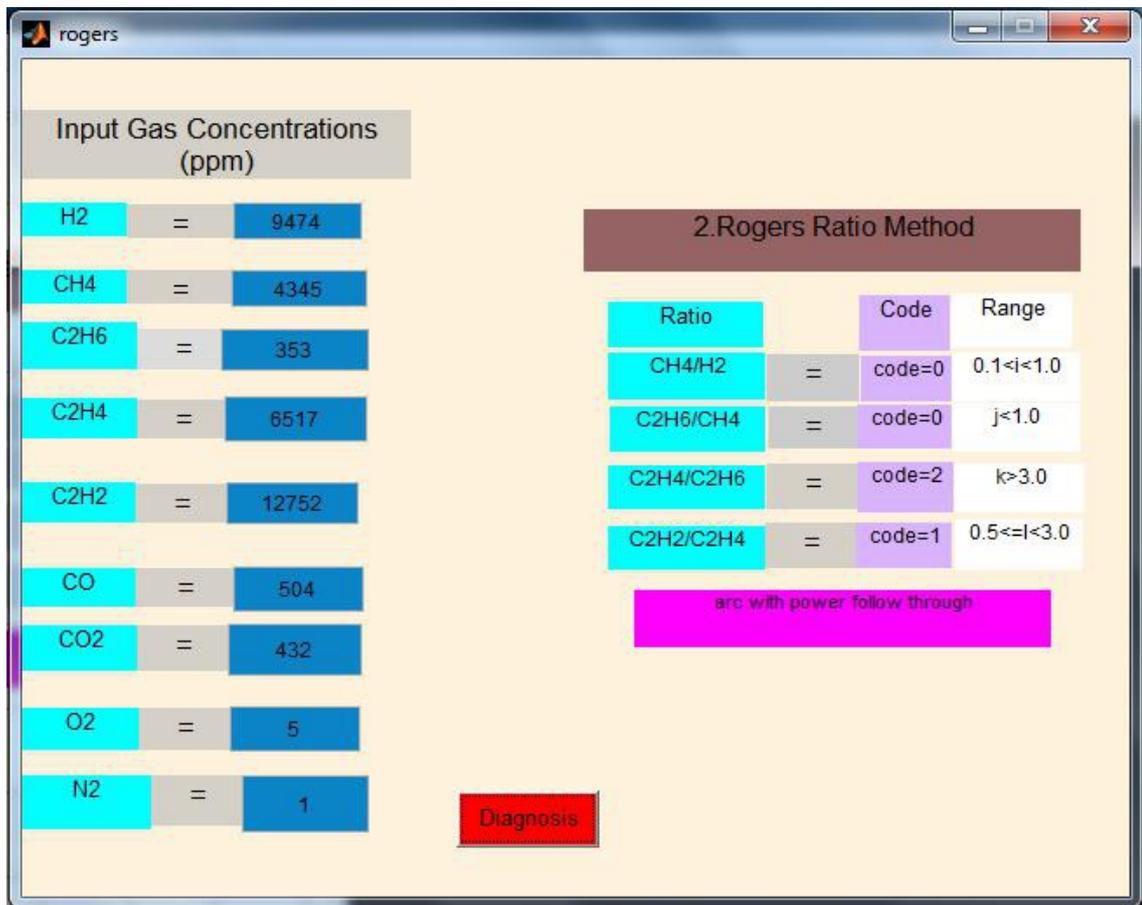
Figure 6.1 Result window of Rogers Ratio Method using MATLAB GUI

6.1.4 Result and Discussions

By taking the same sample input data used in key gas method shown in Table 5.1, Rogers's ratio method diagnosis the condition as "arc with power follow through". Figure 6.1 shows the Rogers ratio GUI result, taking nine gases concentrations as input it gives fault condition by momentum diagnosis button clicked. This result also gives each gas ratios range followed by corresponding code.

The GUI result for given sample unit in Figure 6.1 are
CH_4/H_2 gases ratio range is $0.1<i<1$ and corresponding code representation as code=0
C_2H_6/CH_4 gases ratio range is $j<1.0$ and corresponding code representation as code=0
C_2H_4/C_2H_6 gases ratio range is $k>3.0$ and corresponding code representation as code=2
C_2H_2/C_2H_4 gases ratio range is $0.5<=l<3.0$ and corresponding code representation as code=1
Hence finally it given fault condition as "Arc with power follow through"

Manually also verified this result by seeing the all gas ratios ranges and code displayed in Table 6.3, it also shows fault condition for corresponding codes show in Figure 6.1 as "arc with power follow through".

6.2 IEC Ratio Analysis

6.2.1 Introduction

IEC stands International Electro Technical Commission. It is also similar to Rogers ratio method expect one ratio dropped is C_2H_6/CH_4. By considering these three gas ratios, it diagnosis the faults conditions as thermal faults in various ranges (300^0C-700^0C), electrical faults like low energy and high energy cases, normal ageing. As like in previous method (Rogers's ratio method) here also there is no consideration about combination of both thermal and electrical faults [9].

6.2.2 Diagnosis Codes Representation

It is taking similar ratios of Rogers's ratio method except C_2H_6/CH_4; even it is similar ratios of Roger's ratio method but does not diagnosis the same faults because it considered different ranges for corresponding gas ratios. Hence the ratio ranges and their code representation and

The indication of faults for every case is different compare to Roger's ratio method [6]. Table 6.4 indicates ratio codes, gas ratio ranges in ppm and their code representation to MATLAB GUI program [3].

TABLE 6.4: IEC RATIO CODE REPRESENTATION

Ratio code	Range	Code
$I(C_2H_2/C_2H_4)$	<0.1	0
	0.1-3.0	1
	>3.0	2
$j\ (CH_4/H_2)$	<0.1	1
	0.1-1.0	0
	>1.0	2
$k(C_2H_4/C_2H_6)$	<1.0	0
	1.0-3.0	1
	>3.0	2

Hence by using Table 6.4 gas ratio ranges, developed eight cases of fault conditions such as Shown in Table 6.5 and this Table 6.5 indicates entire type of faults for corresponding code Ranges of gas ratios.

TABLE 6.5: TOTAL POSSIBLE DIAGNOSIS FAULTS FOR IEC RATIO METHOD

SL.NO $I(C_2H_2/C_2H_4)$		$j(CH_4/H_2)$	$k(C_2H_4/C_2H_6)$	Diagnosis
1	0	0	1	Normal ageing
2	>0	1	0	Partial discharge of low energy density
3	1	1	0	Partial discharge of high energy density
4	1-2	0	1-2	Discharge of low energy
5	1	0	2	Discharge of high energy
6	0	0	1	Thermal fault($<150^0$c)
7	0	2	0	Thermal fault(150^0c-300^0c)
8	0	2	1	Thermal fault(300^0c-700^0c)
9	0	2	2	Thermal fault($>700^0$c)

6.2.3 IEC Ratio Method Software implementation to MATLAB GUI

Figure 6.2 represents flow chart to developed MATLAB GUI program, it showing all codes representation and its ranges. Hence by implementing this method in MATLAB GUI can diagnosis the incipient faults at one window. Figure 6.3 shows MATLAB GUI result for IEC ratio method. GUI result gives all corresponding gas ratios range and their code and status of the mineral oil i.e. whether it is faulty or not and finally it gives incipient fault type at one window by using ratios ranges.
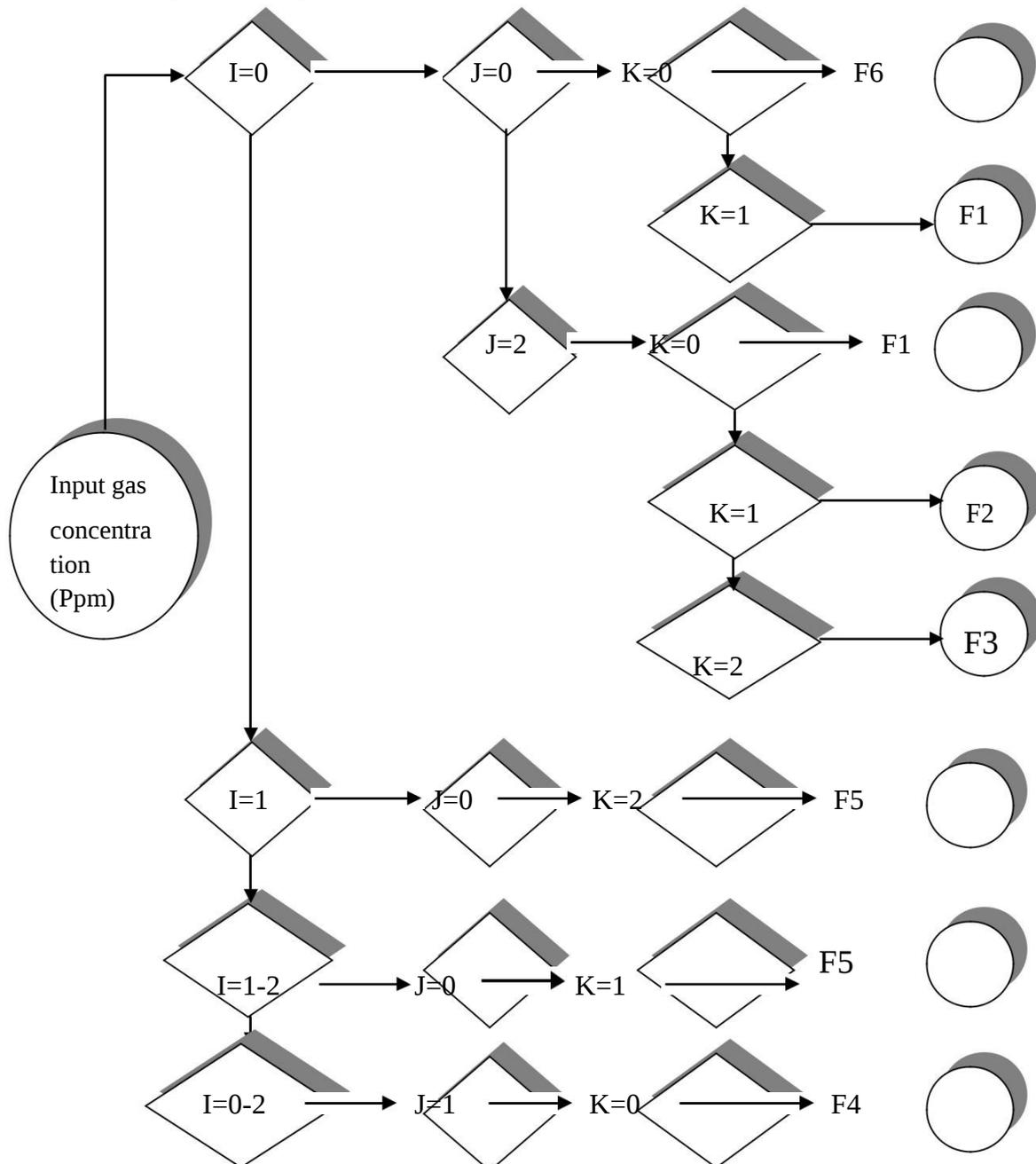
Figure 6.2: Flow Chart of Identification of gases present in Transformer oil using IEC Ratio Method

Input Gas Concentrations (ppm)

H2	=	9474
CH4	=	4345
C2H6	=	353
C2H4	=	6517
C2H2	=	12752
CO	=	504
CO2	=	432
O2	=	5
N2	=	1

3. IEC Ratio Method

IEC ratio analysis result indicate below is more significant

Ratio		code	Range
C2H2/C2H4	=	code=1	0.1<l<3.0
CH4/H2	=	code=2	i>3.0
C2H4/C2H6	=	code=2	k>3.0

No Prediction

Diagnosis

Figure 6.3 Result window of IEC Ratio Method using MATLAB GUI

6.2.4 Result and Discussions

By taking the same sample input data used in key gas method shown in Table 5.1, IEC ratio method diagnosis the condition as "No Prediction" means IEC method _**fails**_ to diagnosis the fault condition. Figure 6.3 shows the IEC ratio GUI result, taking nine gases concentrations as input it gives fault condition by momentum diagnosis button clicked. This result also gives each gas ratios range followed by corresponding code. The GUI result for given sample unit in Figure 6.3 are

C_2H_2/C_2H_4 gases ratio range is 0.1<l<3.0 and corresponding code representation as code=1
CH_4/H_2 gases ratio range is i>3.0 and corresponding code representation as code=2
C_2H_4/C_2H_6 gases ratio range is k>3.0 and corresponding code representation as code=2
Finally GUI result shows No Prediction i.e. IEC ratio method is failed to diagnosis the faults
For this sample.

   Manually also verified this result by seeing the all gas ratios ranges and code displayed in Table 6.5, it also shows same fault condition for corresponding codes show in Figure 6.3 as not valid.

6.3 Doernenburg Ratio Method

6.3.1 Introduction

This technique used four different gas ratios such as C_2H_6/C_2H_2, CH_4/H_2, C_2H_2/CH_4 and like C_2H_2/C_2H_4. Taking these gas ratios ranges, it diagnosis the different fault conditions 6.6 partial discharge, arcing and thermal faults in various degree of severity [9]. Table indicates the minimum level of gas concentrations for key gases used in this method [11].

TABLE 6.6: CONCENTRATION LIMITS OF DISSOLVED GAS [11]

Key Gas	Concentration (ppm)
Acetylene(C_2H_2)	35
Methane(CH_4)	120
Ethylene(C_2H_4)	50
Hydrogen(H_2)	100
Carbon Monoxide(CO)	350
Ethane(C_2H_6)	65

TABLE 6.7: RATIOS FOR KEY GASES IN DOERNENBURG METHOD [6]

Suggest Fault	$P(CH_4/H_2)$		$Q(C_2H_2/C_2H_4)$		$R(C_2H_6/C_2H_2)$		$S(C_2H_2/CH_4)$	
Diagnosis								
Thermal Decomposition	>1.0	>0.1	<0.75	<1.0	<0.3	<0.1	>0.4	>0.2
Corona (low intensity PD)	<0.1 <0.001		Not significant		<0.3	<0.1	>0.4 >0.2	
Arcing (high intensity PD)	>0.1	>0.01	>0.75	>1.0	>0.3	>0.1	<0.4 <0.2	

Table 6.7 indicates the total possible diagnosis faults by taking gases ratios ranges such as Thermal Decomposition, Corona (low intensity PD) and Arcing (High intensity PD).

6.3.2 Doernenburg Ratio Software implementation to MATLAB GUI

6.3.2.1 Step by step procedure

Step 1: Collect sample unit and extract the dissolved gases and find the gas concentrations byusing Gas Chromatographic.

Step 2: If at least one of the gas concentrations (ppm) overcomes twice the values forLimits (see in Table 6.6) and one of the other three gases exceeds the values for limits shown in Table 6.6, the sample is considered faulty; proceed to Step 3 to determine validity of the ratio procedure

Step 3: If at least one of the gases for corresponding gas ratios in Table 6.7 (P, Q, R and S) more than limits in Table 4.6, this method is valid otherwise this method is not valid and shows "No Prediction".

Step 4: Each ratio is compared to the values obtained in Table 6.7 in the order P, Q, R, and S.If all succeeding ratios for a specific fault type fall within the values given in Table 6.7, the suggested diagnosis are valid [11]. Hence this entire process represent in flow chart show in Figure 6.4.
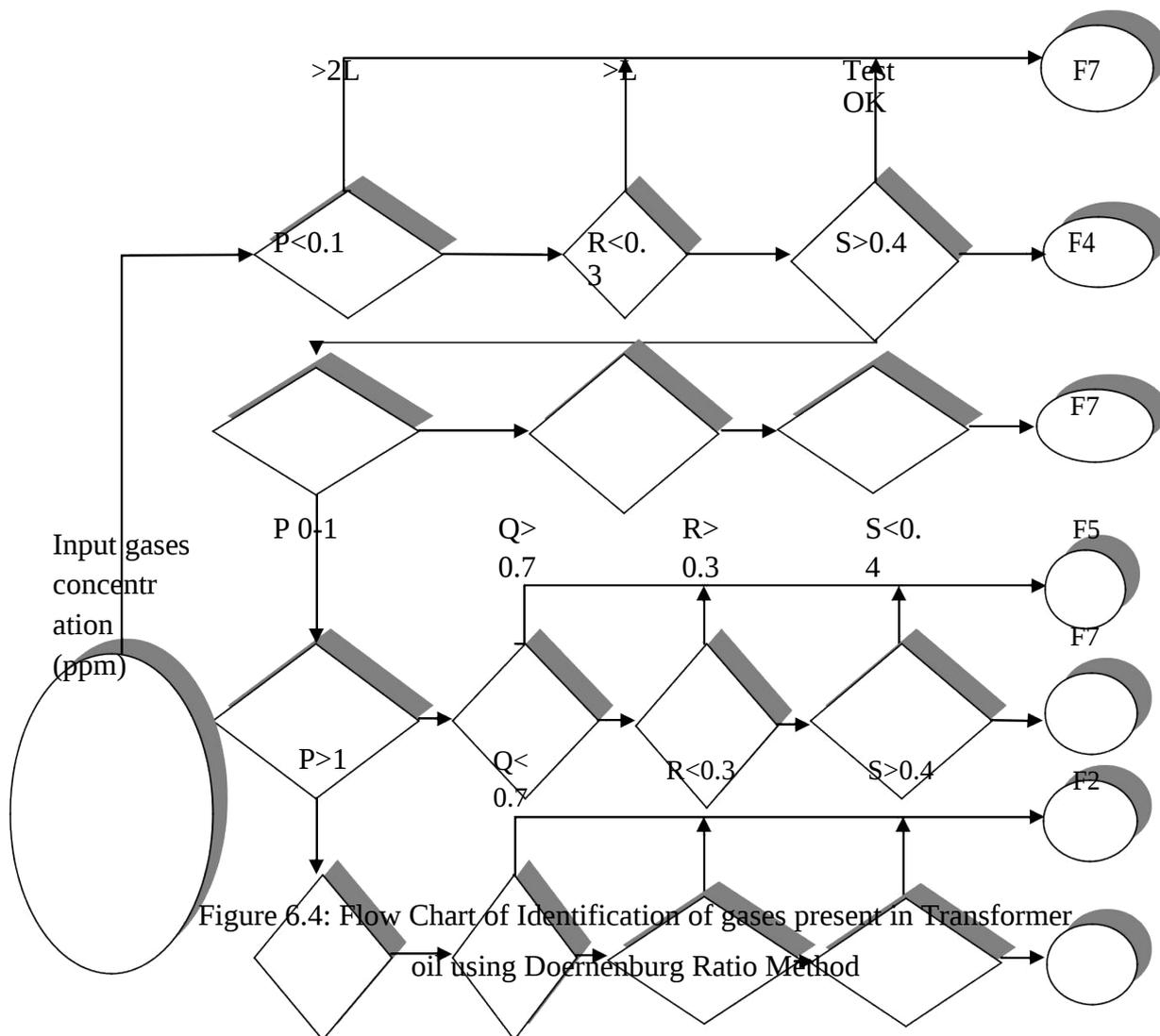
Figure 6.4: Flow Chart of Identification of gases present in Transformer oil using Doernenburg Ratio Method

Figure 6.4 represents flow chart to developed MATLAB GUI program, it showing all codes representation and its ranges. Hence by implementing this method in MATLAB GUI can diagnosis the incipient faults at one window. Figure 6.5 shows MATLAB GUI result for Doernenburg ratio method. GUI result gives all corresponding gas ratios range and their code and status of the mineral oil i.e. whether it is faulty or not and finally it gives incipient fault type at one window by using ratios ranges.
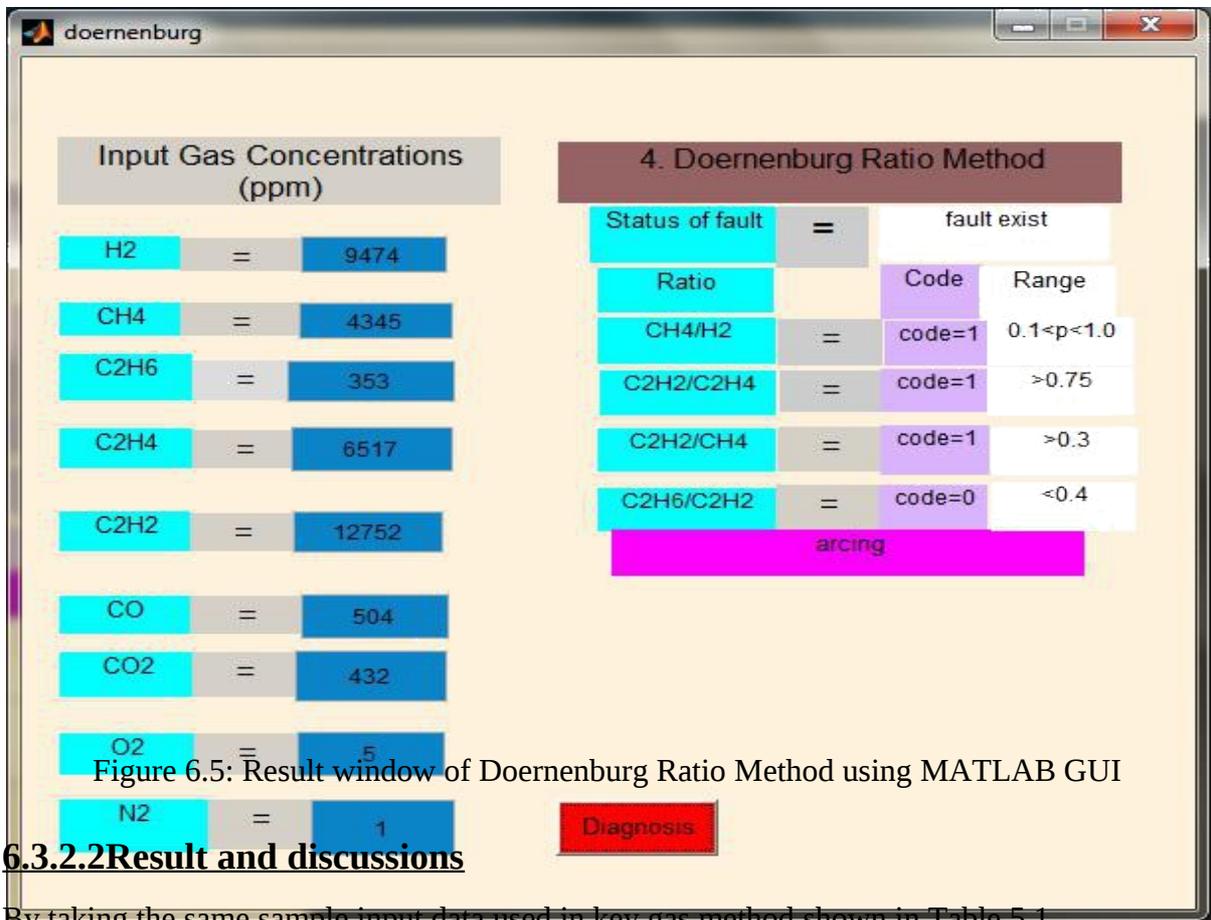
Figure 6.5: Result window of Doernenburg Ratio Method using MATLAB GUI

6.3.2.2 Result and discussions

By taking the same sample input data used in key gas method shown in Table 5.1, Doernenburg ratio method diagnosis the fault condition as "Arcing". Figure 6.5 shows the Doernenburg ratio GUI result; taking nine gases concentrations as input it gives fault condition. This result also gives each gas ratios range followed by corresponding code. The GUI result for given sample unit in Figure 6.5 are

CH_4/H_2 gases ratio range is 0.1<P<1 and corresponding code representation as code=1

C_2H_2/C_2H_4 gases ratio range is Q>0.7 and corresponding code representation as code=1

C_2H_2/CH_4 gases ratio range is R<0.3 and corresponding code representation as code=1

C_2H_6/C_2H_2 gases ratio range is S<0.4 and corresponding code representation as code=0

Finally GUI result diagnosis the fault condition as "Arcing". Manually also verified this result by seeing the all gas ratios ranges and code displayed in Table 6.7, it also shows fault condition for corresponding codes show in Figure 6.5 as "Arcing".

Chapter 7

DUVAL TRIANGLE METHOD FOR DISSOLVED GAS ANALYSIS

Overview:

Present chapter deals with most accuracy DGA interpretation technique among all classical diagnostic techniques – Duval Triangle Method and also describes zones representation for all type of faults to Duval Triangle and their software implementation to MATLAB GUI

7.1 Introduction

Duval Triangle Technique for oil filled high voltage power transformer was developed by Michel Duval in early years of 1970's. Instead of taking all dissolved gases, it takes only three gases such as CH_4, C_2H_4 and C_2H_2 and these three gases relative percentage gives status of power transformer. It is the graphical representation of fault determination is performed focused around visualization of the area of broke down gasses in the triangular map. The main merit of this technique is "it is always diagnosis the faults with low rate of wrong results'' [6]. Figure 7.1 indicates the Duval Triangle representation of three types of faults such as Thermal Faults in various ranges, low and high energy densities and partial discharge. These three types of faults is categorized into seven zones like D1, D2, T1, T2, T3, PD and DT shown in Table 7.1. Here there is no region for indicating the normal condition, so careless use of Duval Triangle gives any type fault condition among seven diagnosis incipient faults conditions. So before going to diagnosis the incipient faults using Duval Triangle Method check the key gases (CH_4, C_2H_4 and C_2H_2) concentrations and follow the steps shown in 7.2 Example. The three sides of triangle mentioned in Figure 7.1 are $\%CH_4$, $\%C_2H_4$, and $\%C_2H_2$ and these values should be within 0 to 100% for each gas [5].
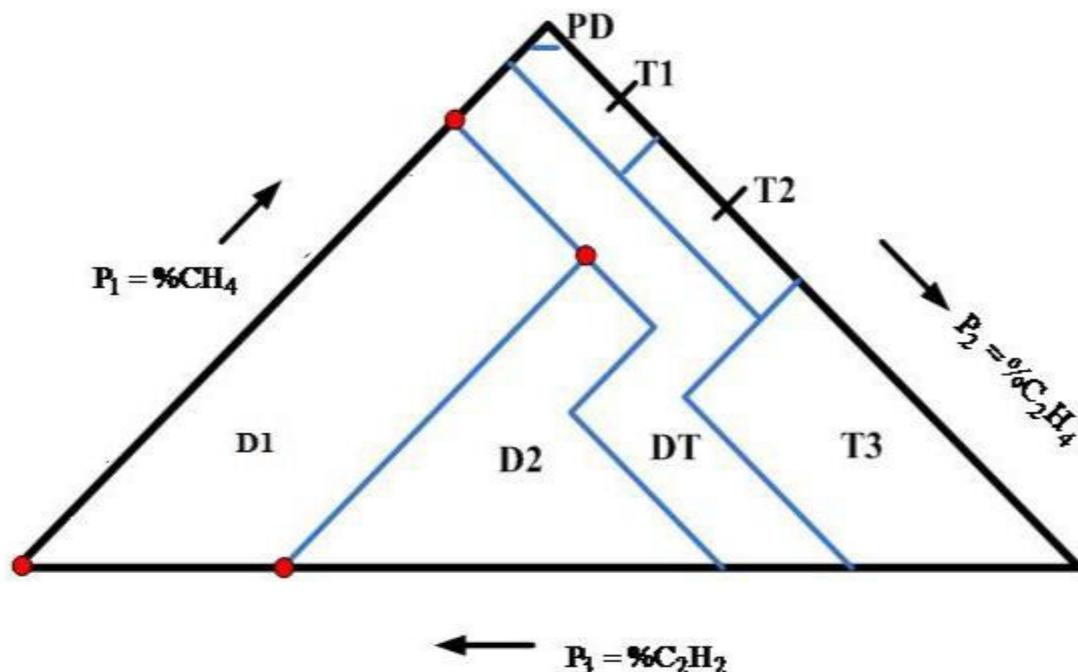
Figure 7.1: Duval Triangle Method representation of three types of fault zones

TABLE 7.1: DUVAL TRIANGLE DETECTABLE POSSIBLE FAULTS [8]

Symbol	Fault Code	Examples
PD	Partial Discharge	Cold plasma discharges(corona), voids (or) Gas Bubbles
D1	Discharge of low Energy	Partial Discharges of sparking type like carbonized punctures, pinholes.
D2	Discharge of High Energy	Discharges in oil or paper,
T1	Thermal Fault $<300^0$C	Evidenced by paper turning brownish
T2	Thermal fault 300^0C-700^0C	formation of carbon particles, Carbonization of paper
DT	Combination of Electrical and Thermal	Discharges of low energy, pinholes

7.2 Example for Fault Zone Indication

Let say CH_4=a, C_2H_4=b and C_2H_2=c

Step 1: First calculate summation of three key gases concentration as (a+b+c)

Step 2: Calculate the relative percentage of each gas by using following formulas

%CH_4= (a / (a+b+c))*100

%C_2H_4= (b / (a+b+c))*100

%C_2H_2= (c / (a+b+c))*100

Step 3: By considering three gases percentages, draw a parallel lines to corresponding

Sides of triangle. It indicates only one point inside the triangle that shows fault zone.

For instance, take key gases concentrations in ppm as CH_4=60, C_2H_4=120 and

C_2H_2=20 P1=%CH_4=30%,

P2=%C_2H_4=60%,

P3=%C_2H_2=10%

From a percentage of P1 (such as point D) draw a parallel line to BC, from percentage of P2 (such as E) draw a parallel line to CA and from a percentage of P3 (such as F) draw a parallel line to AB and that meeting point shows only one point inside the triangle i.e. fault indication zone for the sample unit. Hence Figure 7.2 shows sample of point shown in a triangle for above example of gases concentrations.
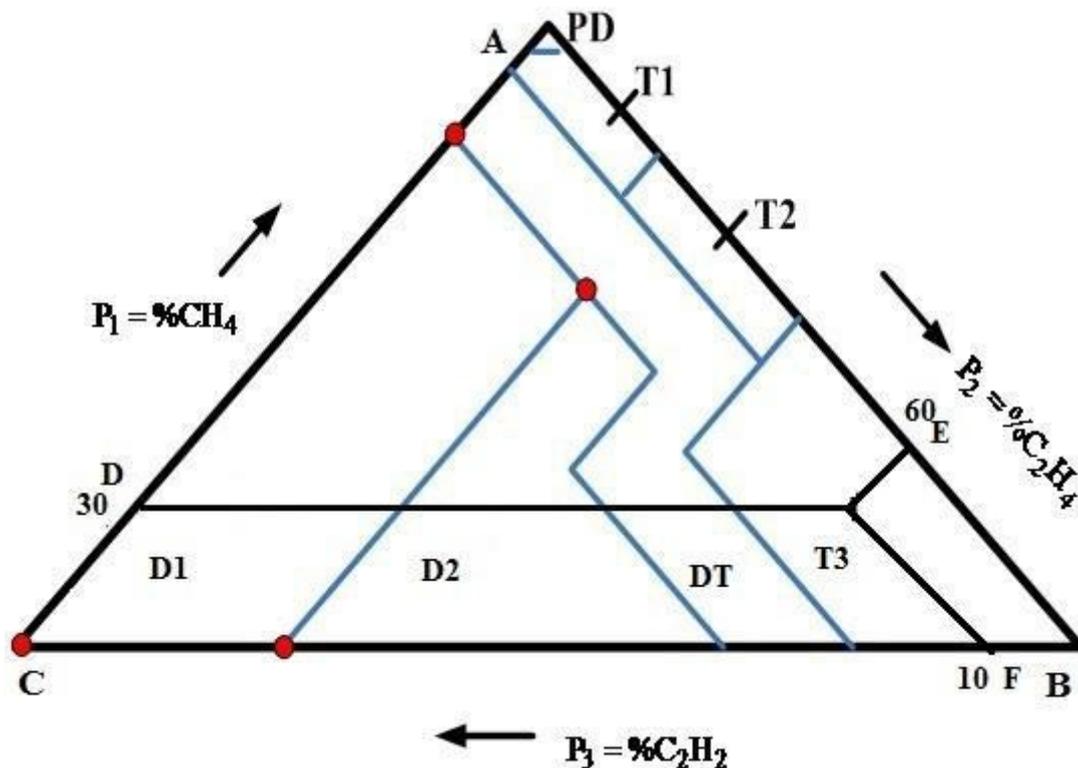
Figure 7.2: Sample of fault zone point showed in a Duval Triangle Method

7.3 Duval Triangle Fault Zones Coordinates

To focus distinctive zones of Duval Triangle, we need to characterize a polygon for each one zone. As indicated in Figure 7.3, we require seven types of polygons to characterize distinctive fault zones. The four points of zone D1 is specified such as D_{11}, D_{12}, D_{13} and D_{14}. Each one point, for example D_{11} is characterized by its fraction values P1, P2 and P3. Figure 5.3 shows all points of every polygon of Duval triangle. Sometimes one point is common for neighboring polygons e.g. points D_{12} and D_{21} of polygons D_1 and D_2 are the same, Table 7.2

Shows Duval triangle coordinates for seven zones of Duval Triangle. To characterize each polygon, the points shown in Table 7.2 should be changed over to Cartesian coordinates utilizing trigonometric properties to represent Duval Triangle in MATLAB.
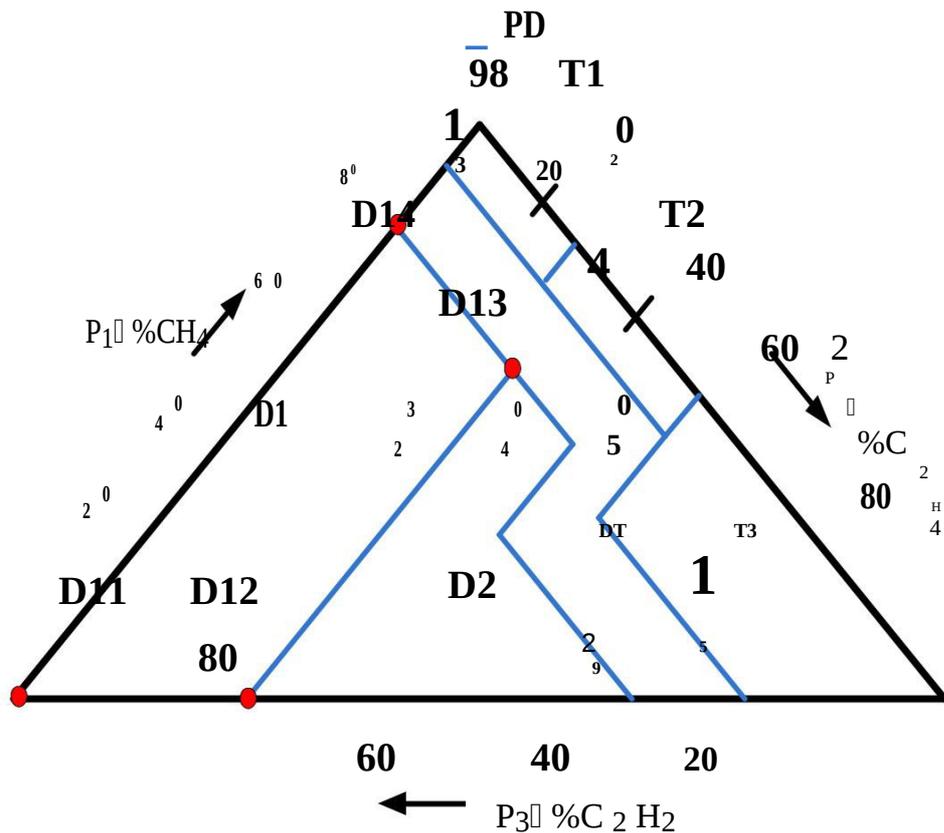
Figure 7.3: Different fault zone coordinates representation of Duval Triangle

Table 7.2 indicates the Duval triangle triangular coordinates for each zone and these coordinates of each zone are translate to Cartesian coordinates to implementation software for Duval Triangle. Each one point of polygon is characterized by its fraction values P1, P2 and P3 (%CH$_4$, %C$_2$H$_4$ and %C$_2$H$_2$).

TABLE 7.2: DUVAL TRIANGLE TRIANGULAR COORDINATES [8]

Area	Points	%CH_4	%C_2H_4	%C_2H_2
D1	D11	0	0	1
	D12	0	0.23	0.77
	D13	0.64	0.23	0.13
	D14	0.87	0	0.13
D2	D21	0	0.23	0.77
	D22	0	0.71	0.29
	D23	0.31	0.40	0.29
	D24	0.47	0.4	0.3
	D25	0.64	0.23	0.13
DT	DT_1	0	0.71	0.29
	DT_2	0	0.85	0.5
	DT_3	0.35	0.5	0.15
	DT_4	0.46	0.5	0.04
	DT_5	0.96	0	0.04
	DT_6	0.87	0	0.13
	DT_7	0.47	0.4	0.13
	DT_8	0.31	0.4	0.29
T_1	T_{11}	0.76	0.2	0.04
	T_{12}	0.8	0.2	0.0
	T_{13}	0.98	0.02	0.0
	T_{14}	0.98	0.02	0.02
	T_{15}	0.96	0.0	0.04
T_2	T_{21}	0.46	0.5	.04
	T_{22}	0.5	0.5	0
	T_{23}	0.8	0.2	0
	T_{24}	0.76	0.2	0.04
T_3	T_{31}	0	0.85	0.15
	T_{32}	0	1	0
	T_{33}	0.5	0.5	0
	T_{34}	0.35	0.5	0.15
PD	PD_1	0.98	0.02	0
	PD_2	1	0	0
	PD_3	0.98	0	0.02

Start

Take the key gas concentrations (ppm)

$C_2H_2>1$, $C_2H_4>50$

$CH_4>120$

Test is not ok

Define each boundary line of Duval Triangle

Calculate the % of CH_4, C_2H_4, and C_2H_2

$P1>98$

Partial Discharge

$P3<4$ — $P2=20-50$ → Thermal Fault 300^0c-700^0c

$P2<20$ → Thermal Fault $<300^0c$

$P3<13$

$P3<23$ → Discharge of low energy

$P3<13$ — $P3>50$ → Thermal Fault$>700^0c$

$P3=29-77$ → $P2=23-40$ → Discharge of High Energy

Mix of Electrical and Thermal Fault
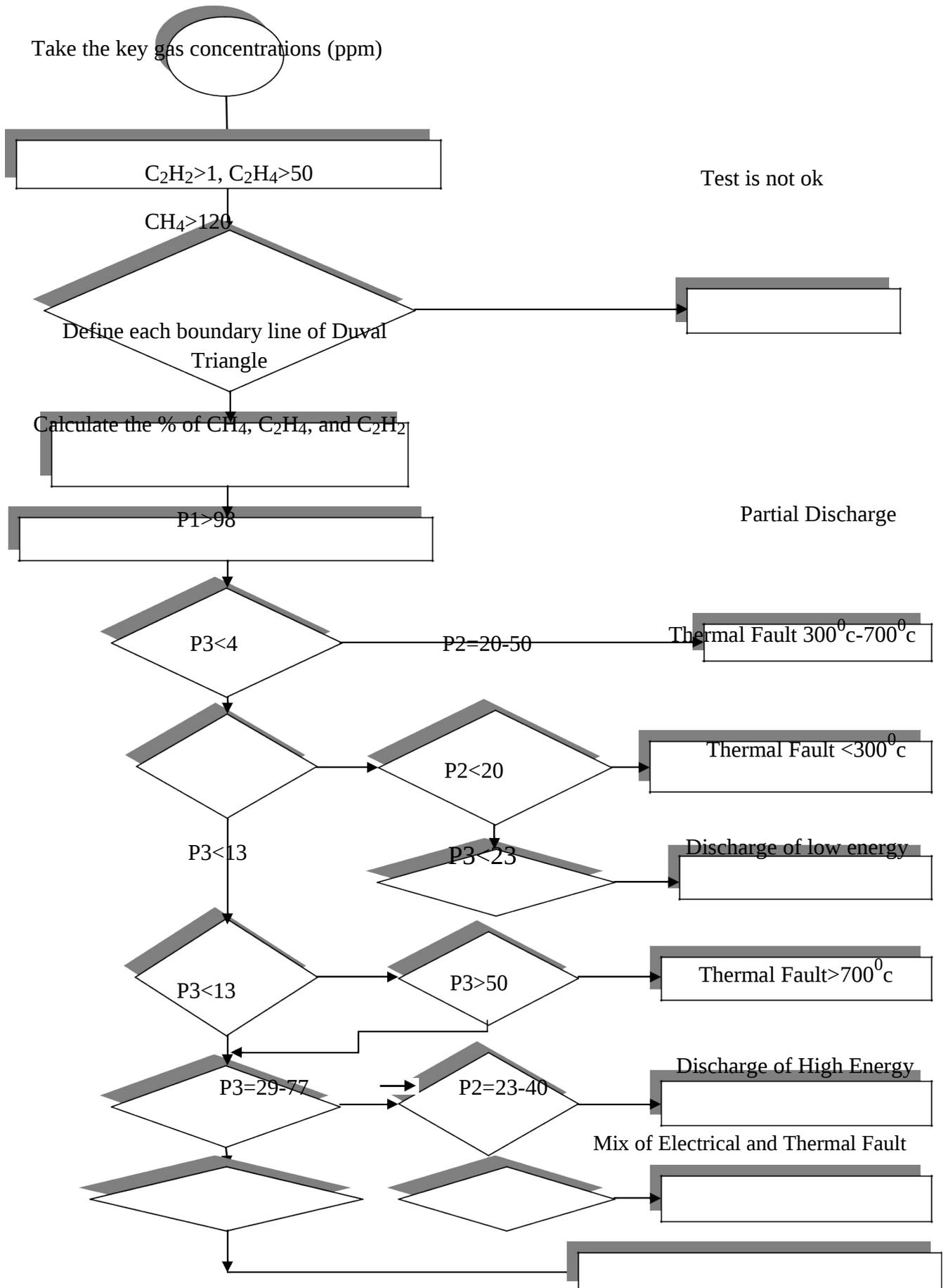
Figure 7.4 Flow chart of Identification of % CH_4, %C_2H_4 and %C_2H_2 gases present in Transformer oil using Duval Triangle Method

7.4 Software Implementation to Duval Triangle

To implement the Duval Triangle a MATLAB program is developed, it gives visual display of all type of fault zones with different color. Taking relative percentage of three incipient gases, it gives only one point and it shows final fault for Duval Triangle method. Figure 7.4 indicates flow chart representation of Duval Triangle Method. In case of Duval Triangle before going to diagnosis the fault condition, it checks for normality of gases concentration shown in Figure 7.4. If it is ok then only it forwards to next steps and diagnosis the faults otherwise simply it shows "Test is not ok".

7.5 Result and Discussions

By taking the same sample input data used in key gas method shown in Table 5.1, Duval Triangle Method gives result in shown in Figure 7.5
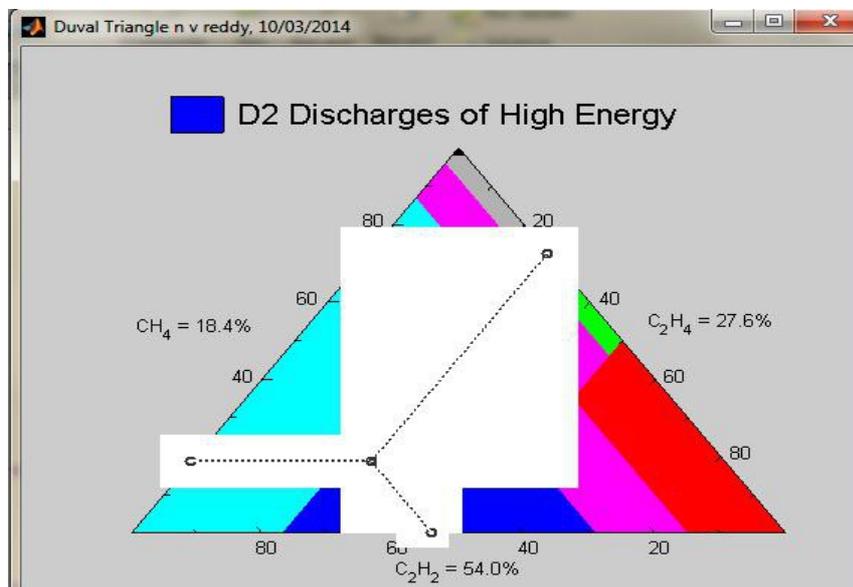
Figure 7.5: Result window of Duval Triangle Method using MATLAB GUI

Figure 7.5 represents the Duval Triangle result for gas concentrations shown in Table 5.1 and it shows the key gases concentrations as %CH_4=18.4, %C_2H_4=27.6 and %C_2H_2=54. Hence it diagnosis the fault condition as "Discharge of High Energy".

Chapter 8

COMBINED DGA METHOD

Overview:

In this chapter mapping process of all incipient faults and their code representation to find common fault are discussed, results of each diagnostic method and their accuracy for Diagnosis the faults are discussed. Also describes about combine DGA method and diagnosis Of incipient faults to combine DGA method. Here 30 samples of data are tested by individual And combine DGA methods by MATLAB GUI program.

8.1 Mapping Process of Faults to each Diagnostic Method

Each individual diagnostic method has been given different fault conditions for same sample unit. For instance, sample unit tested in chapter 3, 4, 5, Key Gas Method got diagnosis condition as "Acing in Oil", Rogers Ratio Method got diagnosis condition as "Arc with Power Follow Through", IEC Ratio Method got result as "No Prediction", Doernenburg Ratio Method got diagnosis condition as "Arcing" and in case of Duval Triangle Method got diagnosis condition as "Discharge of High Energy". So for common fault identification all individual faults are categorized into seven types of faults and these faults assign with a fault codes F1-F7 shown in Table 8.1

TABLE 8.1: TOTAL INCIPIENT FAULTS CATEGORIZED IN TRANSFORMER OIL

SL.NO	Fault Type	Code
1	Thermal faults $<300^0$C	F1
2	Thermal faults 300^0C-700^0C	F2
3	Thermal faults $>700^0$C	F3
4	Partial Discharge	F4
5	Arcing	F5
6	Normal Condition	F6
7	No Prediction	F7

Now each individual method fault types are mapped to F1-F7 for common fault identification. Table 8.2 indicates the mapping process of all individual method faults to 7 seven types of faults and those are indicated as F1-F7.

TABLE 8.2: MAPPING PROCESS OF TRANSFORMER OIL INCIPIENT FAULTS TO EACH DIAGNOSTIC METHOD

Method	F1	F2	F3	F4	F5	F6	F7
Key Gas	No prediction	Principal gas CO, C_2H_4	No prediction	Principal gas H_2	Principal gas C_2H_2	<Limits	No prediction
Rogers Ratio Method	Slight over heating<150C, Overheating 150C-200C	General conductor overheating, core & circulating	Overheating>700C	Partial discharge with tracking	Flash over without power follow, arc with power follow	Normal	No prediction
IEC Ratio Method	Thermal Fault <150C,thermal fault 150C-300C	Thermal Fault 300C-700C	Thermal Fault >700C	Partial discharge of low and high energy density	Arcing and sparking	Normal	No Prediction
Doernenburg Ratio Method	Slight Over heating	Thermal Decomposition	No Prediction	Corona	Arcing	Normal	No Prediction
Duval triangle Method	Thermal Fault <300^{0}C	Thermal Fault 300^{0}C-700^{0}C	Thermal Fault >700^{0}C	Low energy discharged	PD s mix with electrical and thermal	Normal	No Prediction

8.2 Combined DGA Method

In this DGA combined Method considering the merits all individual diagnostic methods and finally diagnosis actual incipient fault. Hence by combines the five classical Techniques, diagnosis of all type faults are possible such as Partial Discharge of with and without arcing,

Thermal Faults with various range (300^0C-700^0C), Discharge of High Energy, Arc with Power follow Through, Arcing and Combination of Electrical and Thermal faults. Finally by using MATLAB GUI software all diagnostic results of individual method and Combined DGA method results displayed at one window.

8.3 Software Implementation to Combine DGA Method

A MATLAB user friendly Graphic User Interface (GUI) is used in this work to represent results of all methods at one window. GUI needs only input data of gas concentrations in ppm. Algorithm divide into different modules to visual display and in which programming calculations where done to find the faults as already programmed. If click on the Diagnosis button on GUI window, all the incipient faults and fault codes of each individual method displayed and type of common fault is displayed with fault code using Combine DGA Method. The result from every technique is the submitted go into the main project program of DGA combine method outline that interfaces the five calculations. The DGA Combine program interface will focus the fault examination analysis classification by using a single fault analysis to find the common fault result.
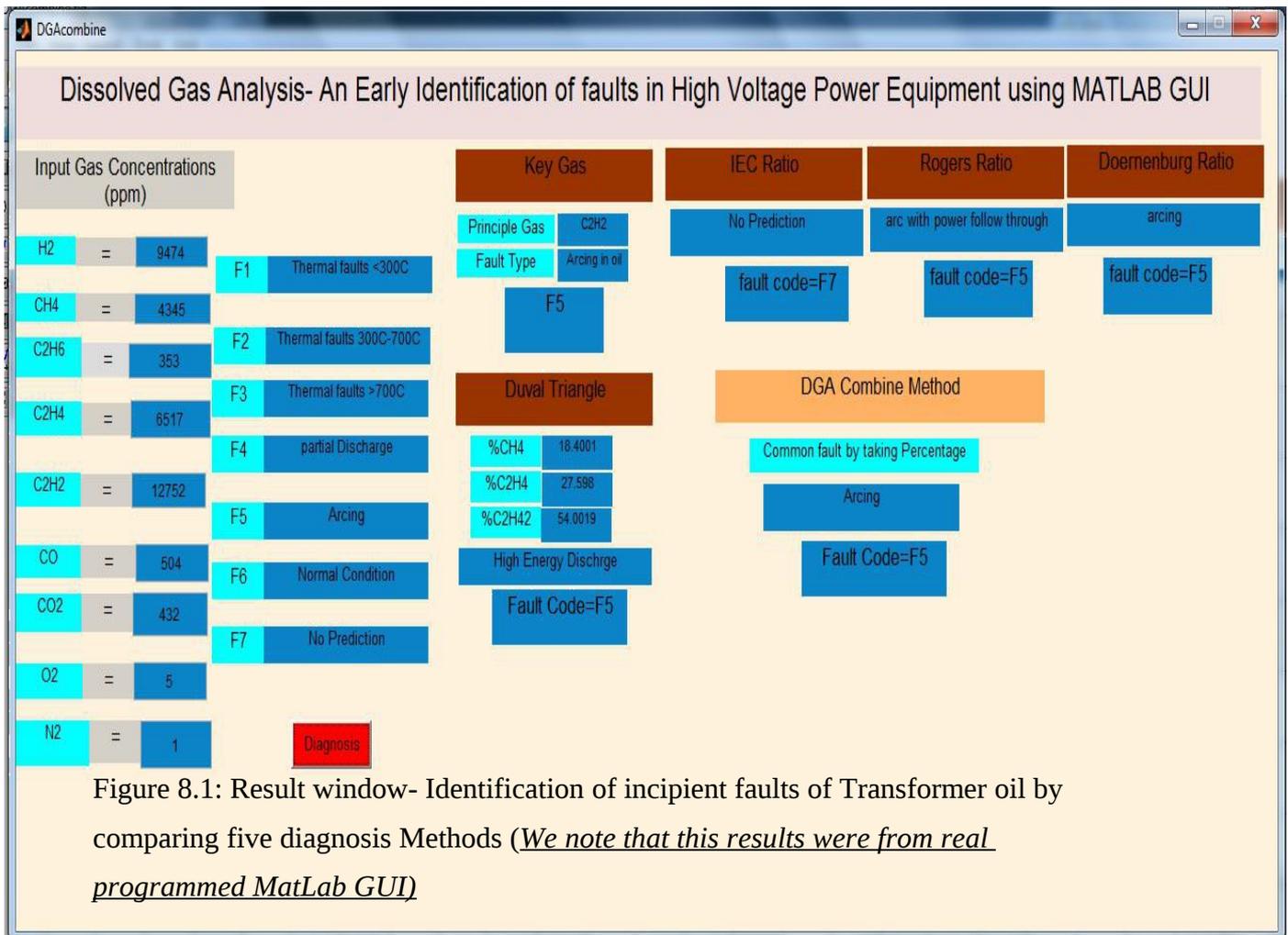
Figure 8.1: Result window- Identification of incipient faults of Transformer oil by comparing five diagnosis Methods (*We note that this results were from real programmed MatLab GUI*)

8.4 Result and Discussions

MATLAB GUI program divided into 3 modules as input concentrations, interpretation methods and Combine DGA Method result for diagnosis the final incipient fault.

Figure 8.1 shows Graphical User Interface display for Key Gas, IEC, Roger's Ratio, Doernenburg Ratio method and Combine DGA Method. By taking the nine gases concentrations (ppm) as input, it gives result for all individual and finally displays the final fault by using combine DGA method. In order to test the software 30 data samples taken from the IEEE reference paper and table 8.3 indicates sample input data and table 8.4 indicates the type of faults diagnosis by all 30 cases for each individual method and combined DGA method. Figure 8.1 indicates MATLAB GUI result of all five individual methods and Combine DGA method.

Taking same sample gas concentrations used in individual methods shown in Table 5.1, Combine DGA Method given results shown in Figure 8.1. Hence for given sample unit, Key

Gas Method diagnosis the condition as "Arcing in Oil" and that it is mapped with fault code F5 see in Table 8.2. Rogers Ratio and Doernenburg Ratio Method diagnosis the condition as "Arc with power follows through" and 'Arcing" simultaneously and it is mapped with fault code is F5 see in Table 6.2 but IEC Ratio method is failed to diagnosis the condition and indicates as "No Prediction" and it is mapped with fault code F7 see in Table 8.2. Duval Triangle method diagnosis the result as "Discharge of High Energy" and it is mapped with fault code F5 see in table 8.2. To get the common fault identification, DGA Combine Method taking the diagnosis results of all individual methods and submitted back into the main program to diagnosis the final fault and it gives final fault by taking the percentage of individual methods. For this sample concentrations shown in Figure 5.1, four individual methods diagnosis the fault code as F5 i.e. Arcing. Hence DGA Combine Method diagnosis the common fault as ''Arcing" by taking percentage of individual methods. It means it releases high amount of acetylene gas corresponding high amount of discharges in oil or paper.

Hence from the above analysis it is clear that MATLAB GUI result of Combine DGA Method diagnosis the exact incipient fault very accurately by combine of all classical individual methods. So by using this prior information of incipient faults, status of oil filled high power equipment can analyze and precautions can take to avoid failure of transformer. In the sense life period of transformer and reliability is increased.

TABLE 8.3: SAMPLE INPUT DATA [18]

SL.NO	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO	CO_2	N_2	O_2
	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
1	24	13	5	43	319	45	43	7	0
2	266	584	328	862	1	230	444	3	2
3	80	619	326	2480	0	1243	463	11	3
4	231	3997	1726	5584	0	553	423	3	1
5	127	24	0	32	81	453	65	2	3
6	9474	4345	353	6517	12752	504	432	5	1
7	507	1053	297	1440	17	3034	235	3	2
8	416	695	74	867	0	150	170	2	4
9	441	207	43	224	261	234	545	1	0
10	65	61	16	143	3	56	74	5	2
11	16	87	75	395	30	300	45	3	1
12	212	38	15	47	78	275	432	2	3
13	800	1393	304	2817	3000	1543	4532	65	15
14	199	770	217	1508	72	453	764	4	3
15	4906	8784	1404	9924	9671	3457	9832	5	7
16	425	17424	7299	37043	158	8753	4679	26	10

17	1076	95	4	71	231	175	543	31	14
18	244	754	172	1281	27	275	453	37	3
19	117	167	48	481	7	532	693	18	42
20	858	1324	208	2743	7672	5432	6543	5	3
21	137	369	144	1242	16	453	658	10	5
22	274	27	5	33	97	32	63	1	2
23	1249	370	56	606	1371	1673	2456	9	4
24	240	20	5	28	96	376	190	4	1
25	33	79	30	215	5	56	64	9	3
26	307	22	2	33	109	465	216	4	2
27	60	144	67	449	9	54	432	10	4
28	2004	9739	2750	5113	0	5642	8734	18	10
29	127	107	11	154	224	236	145	5	1
30	166	10	3	1	1	10	5	1	1

TABLE 8.4: DIAGNOSIS OF FAULTS BY ALL INDIVIDUAL AND COMBINE DGA METHODS

SL.NO	Key	IEC	Rogers	Doernenburg	Duval	Combine
	Gas	**Ratio**	**Ratio**	**Ratio**	**Triangle**	**DGA**
						Method
1	F5	F7	F5	F5	F5	F5
2	F7	F2	F2	F3	F4	F2
3	F3	F3	F3	F2	F3	F3
4	F7	F3	F3	F2	F3	F3
5	F3	F7	F5	F5	F5	F5
6	F5	F7	F5	F7	F5	F5
7	F7	F3	F2	F2	F7	F2
8	F2	F3	F2	F2	F4	F2
9	F7	F7	F5	F5	F5	F5
10	F6	F7	F5	F5	F7	F5
11	F7	F3	F3	F7	F3	F3
12	F7	F7	F5	F5	F7	F7
13	F4	F7	F7	F7	F4	F4
14	**F7**	**F3**	**F3**	**F2**	**F3**	**F3**
15	F7	F7	F7	F7	F5	F7

16	F7	F3	F3	F2	F4	F3
17	F3	F5	F3	F7	F3	F3
18	F7	F3	F3	F2	F3	F3
19	F7	F3	F2	F2	F3	F2
20	F5	F7	F7	F5	F4	F5
21	F3	F3	F2	F2	F7	F2
22	F7	F5	F7	F5	F4	F5
23	F7	F7	F5	F5	F4	F5
24	F5	F5	F7	F7	F4	F5
25	F7	F3	F2	F2	F3	F3
26	F4	F5	F7	F7	F4	F4
27	F7	F3	F2	F2	F7	F2
28	F2	F2	F7	F2	F2	F2
29	F7	F7	F5	F5	F4	F5
30	F6	F4	F4	F5	F4	F4

In order test the software 30 data samples taken from the IEEE reference paper and Table 8.3 indicates the sample input data and Table 8.4 indicates faults diagnosis by each individual method- key Gas, Roger's Ratio, IEC Ratio Method, Doernenburg Ratio Method and Duval Triangle Method for input gas concentrations in ppm and final conclusion of diagnosis fault indicated by combine DGA method.

TABLE 8.5: COMPARING THE PERCENTAGE PREDICTION OF INDIVIDUAL AND DGA COMBINEMETHODS

Method	No of Samples	Results Obtained	No Prediction	Percentage of Prediction
Key Gas	30	13	17	43.34
IEC Ratio	30	19	11	63.34
Rogers Ratio	30	23	7	76.6
Doernenburg Ratio	30	22	8	73.34
Duval Triangle	30	25	5	83.34
DGA Combine Method	30	28	2	93.34

In this work, taking the concentration of key gases (CO_2, CO, H_2, C_2H_2, C_2H_6, C_2H_4 and CH_4) incident faults identified by five classical techniques gives different conditions for the same sample unit used see in Table 8.4. Table 8.5 indicates the percentage prediction of all five classical techniques and DGA Combine Method. Hence Key Gas Method predicts 43% of total incipient fault cases, IEC Ratio method predicts 63% of total incipient fault cases, Rogers Ratio Method predicts 76% of total incipient fault cases, Doernenburg Ratio Method predicts 73% of total incipient fault cases and Duval Triangle Method predicts more than 83% cases of total incipient fault conditions.

Chapter 9

Conclusion

Overview:

In this chapter an attempt has been made to find the fault accurately by combine of all
Classical techniques, it gives condition assessment of power transformer. This chapter discuss
The comparison of all individual techniques accuracy to diagnosis the incipient faults. Also
Describes the accuracy of combine DGA design technique.

9.1 MAIN CONCLUSION

In this work, percentage prediction of all five classical techniques and DGA Combine Method was compared. Hence observed Key Gas Method predicts 43% of total incipient fault cases, IEC Ratio method predicts 63% of total incipient fault cases, Rogers Ratio Method predicts 76% of total incipient fault cases, Doernenburg Ratio Method predicts 73% of total incipient fault cases and Duval Triangle Method predicts more than 83% cases of total incipient fault conditions. In this work, the condition based diagnosis system was developed to combine five DGA assessment classical techniques-Keys Gas Method, IEC Ratio method and Rogers Ratio Method, Doernenburg Ratio and Duval Triangle Method. The result of this method shows overall DGA accuracy to diagnosis the fault is more than 90% compared to 80% of most reliable individual method Duval Triangle. DGA helps to

Diagnosis the present condition of the high voltage power transformer. So by using this prior information about incipient faults, status of oil filled high power equipment can analyze and precautions can take to avoid failure of transformer. In the sense life period of power transformer and reliability has been increased.

9.2 Scope for Future Work

Further, this method is also applicable to other oil filled high voltage power equipment for assessment of its condition during the operating service period of time. This work can develop for Natural Ester and Soy-Seed based oils in future for condition checking purpose of transformer.

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