

Dissolved Gas Analysis–An Early Identification of Faults in High Voltage Power Equipment using MATLAB GUI

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology

In

Electrical Engineering

May 2014

By

N.VEERANJI REDDY
212EE5401



Department of Electrical Engineering
National Institute of Technology, Rourkela

<http://www.nitrkl.ac.in/>

Dissolved Gas Analysis–An Early Identification of Faults in High Voltage Power Equipment using MATLAB GUI

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology

In

Electrical Engineering

May 2014

By

**N.VEERANJI REDDY
212EE5401**

Under the Guidance of

Prof. Subrata Karmakar



Department of Electrical Engineering
National Institute of Technology, Rourkela

<http://www.nitrkl.ac.in/>



DEPARTMENT OF ELECTRICAL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA
ORISSA, INDIA-769008

CERTIFICATE

This is to certify that the thesis entitled “**Dissolved Gas Analysis–An Early Identification of Faults in High Voltage Power Equipment using MATLAB GUI**”, submitted by **Mr. N Veeraji Reddy** in partial fulfillment of the requirements for the award of **Master of Technology in Electrical Engineering** with specialization in “**Industrial Electronics**” at National Institute of Technology, Rourkela. A Bona fide record of research work carried out by him under my supervision and guidance. The candidate has fulfilled all the prescribed requirements. The Thesis which is based on candidates own work, has not submitted elsewhere for a degree/diploma.

In my opinion, the thesis is of standard required for the award of a master of technology degree in Electrical Engineering.

Place: Rourkela

Prof. Subrata Karmakar

Date:

Dept. of Electrical Egg.

National Institute of Technology

Rourkela – 769008

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my supervisor **Prof. Subrata Karmakar** for his guidance, encouragement, and support throughout the course of this work. It was a valuable learning experience for me to be one of his students. From him I have gained not only extensive knowledge, but also a sincere research attitude.

I express my gratitude to **Prof. A. K. Panda**, Head of the Department, Electrical Engineering for his valuable suggestions and constant encouragement all through the research work.

My thanks are extended to my colleagues in Industrial Electronics, who built an academic and friendly research environment that made my study at NIT, Rourkela most memorable and fruitful.

I would also like to acknowledge the entire teaching and non-teaching staff of Electrical Department for establishing a working environment and for constructive discussions.

Finally, I am always indebted to all my family members, especially my parents, for their endless love and blessings.

N VEERANJI REDDY

Roll No: 212EE5401

Department of Electrical Engineering

National Institute of Technology

Rourkela-769008

TABLE OF CONTENTS

ABSTRACT	I	
LIST OF ABBREVIATIONS	II	
LIST OF FIGURES	III	
LIST OF TABLES	IV	
CHAPTER 1	INTRODUCTION	1
OVERVIEW		1
1.1 Introduction		1
1.2 Motivation		2
1.3 Thesis main objectives		3
1.4 Organization of thesis		3
CHAPTER 2	GAS FORMATION IN MINERAL OIL	4
OVERVIEW		4
2.1 Literature Review		5
2.1.1 Total Combustible Gas (TCG)		5
2.1.2 Gas Blanket Analysis (GBA)		5
2.1.3 Dissolved Gas Analysis (DGA)		5
2.2 DGA block diagram		6
2.3 Gas Formation in Mineral oil		7
2.3. I Cellulose Decomposition		7
2.3. II Oil Decomposition		7
2.4 Interpretation of Gas Analysis		8
2.4. I Thermal faults		8
2.4. II Electrical faults		8

CHAPTER 3 GAS INTERPRETATION TECHNIQUES	10
OVERVIEW	10
3.1 Block Diagram to DGA	11
3.2 Key Gas Method	12
3.2 Thermal Faults	12
3.2.1. I Thermal faults in oil	12
3.2.1. II. Thermal faults in cellulose	13
3.3 Electrical Faults	13
3.3. I Corona	13
3.3. II Arcing	14
3.4 Key Gas Method software implementation to MATLAB GUI	16
3.5 Result and discussions	16
CHAPTER 4 RATIO METHODS TO INTERPRETATION OF DGA	18
OVERVIEW	18
4.1 Rogers Ratio Method	19
4.1.1 Introduction	19
4.1.2 Diagnostic Code Representation	19
4.1.3 Rogers ratio method software implementation to MATLAB GUI	20
4.1.4 Result and Discussions	22
4.2 IEC Ratio Analysis	22
4.2.1 Introduction	22
4.2.2 Diagnostic Code Representation	22
4.2.3 IEC ratio method software implementation to MATLAB GUI	24
4.2.4 Result and Discussions	25
4.3 Doernenburg Ratio Method	26
4.3.1 Introduction	26

4.3.2 Doernenburg ratio software implementation to MATLAB GUI	27
4.3.2.1 Step by Step procedure	27
4.3.2.2 Result and Discussions	29
CHAPTER 5 DUVAL TRIANGLE METHOD FOR DISSOLVED	30
GAS ANALYSIS	
OVERVIEW	30
5.1 Introduction	31
5.2 Example of fault zone indication	32
5.3 Duval triangle fault zones coordinates	33
5.4 Software implementation of Duval triangle	37
5.5 Result and Discussions	37
CHAPTER 6 COMBINED DGA METHOD	38
OVERVIEW	38
6.1 Mapping Process Faults to each Diagnostic Method	39
6.2 Combined DGA Method	41
6.3 Software implementation to Combined DGA Method	41
6.4 Results and discussions	42
CHAPTER 7 CONCLUSION	46
OVERVIEW	46
7.1 Conclusion	47
7.2 Scope for Future	47
REFERENCES	48

ABSTRACT

In entire power transmission network transformer plays an important role, it transmits the power from one circuit to another circuit. Transformer protection attains much more attention in order fault free electric supply, efficiency and to maximize the transformer life period. When the mineral oil is subjected to high thermal and electrical stresses, gasses are created from the decay of the mineral oil. Distinctive sort of faults will create diverse gasses, and the dissection of these gasses will give helpful data about the state of the oil and the diagnosis of the type of fault in the transformer. Identification of incipient faults inside the power transformer reduces its failure rate during the long service period. The Dissolved Gas Analysis (DGA) is proved accuracy method all over the world for condition assessment of power transformer. Taking the concentration of key gases (CO, CO₂, H₂, C₂H₆, C₂H₄, C₂H₂ and CH₄) incident faults identified by various classical techniques gives different conditions for the same sample unit. This thesis presents MATLAB GUI program based high accuracy design technique taking the merits of all classical methods. The condition based diagnosis system developed to combine five DGA assessment classical techniques- Key Gas Method, IEC Ratio method, Doernenburg Ratio Method, Duval triangle Method and Rogers Ratio Method. A feasible GUI conferred to give visual display of five methods. The result of this method shows overall DGA accuracy is more than 90% compared to 80% of most reliable individual method Duval Triangle. 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.

LIST OF ABBREVIATIONS

GUI	Graphic User Interface
DGA	Dissolved Gas Analysis
TCG	Total Dissolved Gas
GBA	Gas Blanket Analysis
H ₂	Hydrogen
N ₂	Nitrogen
O ₂	Oxygen
H ₂ O	Water
CO	Carbon Monoxide
CO ₂	Carbon Dioxide
C ₂ H ₂	Acetylene
CH ₄	Methane
C ₂ H ₆	Ethane
C ₂ H ₄	Ethylene

LIST OF FIGURES

Figure No	Figure Name	Page No
Figure 2.1:	Flow Chart of DGA	6
Figure 3.1:	Block diagram of Combine Dissolved Gas Analysis (DGA) Method	11
Figure 3.2:	Approximate percentage (%) of gases found during thermal faults in oil inside the Transformer	12
Figure 3.3:	Approximate percentage (%) of gases found during thermal faults in Cellulose inside the Transformer	12
Figure3.4:	Approximate percentage (%) of gases found during Corona in oil inside the Transformer	14
Figure 3.5:	Approximate percentage (%) of gases found during Arcing in oil inside the Transformer	14
Figure 3.6:	Flow Chart of Identification of gases present in Transformer oil using Key Gas Method	15
Figure 3.7:	Result window of Key Gas Method using MATLAB GUI	16
Figure 4.1:	Result window of Rogers Ratio Method using MATLAB GUI	21
Figure 4.2:	Flow Chart of Identification of gases present in Transformer oil using IEC Ratio Method	24
Figure 4.3:	Result window of IEC Ratio Method using MATLAB GUI	25
Figure 4.4:	Flow Chart of Identification of gases present in Transformer oil using Doernenburg Ratio Method	28
Figure 4.5:	Result window of Doernenburg Ratio Method using MATLAB GUI	29
Figure 5.1:	Duval Triangle Method representation of three types of fault zones	31
Figure 5.2:	Sample of fault zone point showed in a Duval Triangle Method	33
Figure 5.3:	Different fault zone coordinates representation of Duval Triangle	34
Figure 5.4:	Flow chart of Identification of % CH ₄ , % C ₂ H ₄ and % C ₂ H ₂ gases present in Transformer oil using Duval Triangle Method	36
Figure 5.5:	Result window of Duval Triangle Method using MATLAB GUI	37
Figure 6.3:	Result window- Identification of incipient faults of Transformer oil by comparing five diagnosis Methods	41

LIST OF TABLES

Table No	Table Name	Page No
Table 3.1:	Input gases and concentration in ppm	17
Table 3.2:	Limitation of key gas method	17
Table 4.1:	Rogers ratio method ratios code representation	19
Table 4.2:	Rogers ratio code representation	20
Table 4.3:	Rogers ratio total possible diagnosis faults	20
Table 4.4:	IEC Ratio Code Representation	23
Table 4.5:	IEC ratio total possible diagnosis faults	23
Table 4.6:	Concentration limits of Dissolved Gas	26
Table 4.7:	Ratios for Key Gases in Doernenburg Method	27
Table 5.1:	Duval Triangle detectable possible faults	32
Table 5.2:	Duval Triangle triangular coordinates	35
Table 6.1:	Total incipient faults categorized in Transformer oil	39
Table 6.2:	Mapping Process of transformer incipient faults to each Diagnostic Method	40
Table 6.3:	Sample input data	43
Table 6.4:	Diagnosis of faults by all individual Methods and Combine DGA Method	44
Table 6.5:	Comparing the percentage prediction of individual methods and DGA Combine Method	45

Chapter 1

INTRODUCTION

Overview:

Present chapter describes the introduction of project work. Also describes about main motivation of this work followed by main objectives. This chapter also describes the organization of thesis.

1.1 Introduction

In entire power transmission network transformer plays an important role, it transmits the power from one circuit to another circuit. So transformer protection attains much more attention in order fault free electric supply, maximize transformer life period and efficiency. Actually mineral oil treats heart of the transformer, it serves mainly insulation and cooling purpose but among that it is use to detect the fault gases dissolved in oil. The identification of specific gasses created in a transformer in administration is regularly the first accessible sign of a malfunction. If these faults are not correct, transformer may goes to failure. This is not encourage thing, it may cause to damage entire power transmission and not economical. Before failure of transformer, detection of fault is better option. So Dissolved Gas Analysis (DGA) is proved accuracy method to find faults. DGA mainly involves extracting or stripping of oil from the unit and subject to Gas Chromatography to extract the dissolved gases from oil [1]. The second step of DGA is detection of gas concentration levels using suitable methods like Flame Ionization detector, Thermal conduction detector (FID, TCD) and analyze for faults by using suitable diagnostic methods to find cause [2].

In this work, the condition based diagnosis system developed to combine five DGA classical methods-Keys Gas Method, Rogers Ratio Method, IEC Ratio method, Doernenburg ratio method and Duval triangle method. A feasible MATLAB GUI conferred to give visual display of five methods. The result of this method shows overall DGA accuracy is more than 90% compared to 80% of most reliable individual method. DGA helps to diagnosis the present condition of the high voltage power transformer. 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.

1.2 Motivation

Dissolved Gas Analysis (DGA) has most proved accuracy method for condition assessment of power transformer. This gives prior information regarding mineral oil degradation level and generated dissolved gasses in mineral oil and concentration of dissolved gases by using Gas Chromatography. Taking the concentration of key gases (CO, CO₂, CH₄, C₂H₆, C₂H₂, H₂ and C₂H₄) incident faults identified by various classical techniques gives different conditions for the same sample unit. In this work considered

the point, which discussed in above line and design combine of all five diagnosis methods for better accuracy results to diagnosis of incipient faults.

1.3 Thesis Main Objectives

- ✓ Analyze five classical diagnosis techniques to identify incipient faults in Transformer oil using 1. Key Gas method, 2. Rogers's Ratio Method, 3. Doernenburg Ratio Method, 4. IEC Ratio Method and 5. Duval Triangle Method
- ✓ Develop MATLAB GUI software for each diagnosis method and compare accuracy.
- ✓ Design combine five diagnosis methods of DGA for condition assessment of Power Transformer.

1.4 Organization of Thesis

The entire thesis organization is as follows

Chapter 1: Deals with introduction of entire work follows by motivation and also discussed about main objectives of this work and finally organization of thesis are discussed

Chapter 2: Deals with gas formation in mineral oil, degradation level and factors Effect on mineral oil for dissolved gases.

Chapter 3: Deals with DGA interpretation techniques and the block diagram model design Of DGA combined five methods and also it deals with one of the interpretation Technique -Key gas method.

Chapter 4: Deals with DGA interpretation techniques like Roger's ratio, IEC ratio, Doernenburg ratio methods and their codes representation for each method

Chapter 5: Deals with most accuracy DGA interpretation technique Duval's triangle method and its zones representation for all type of faults are discussed.

Chapter 6: Deals with mapping process of all type of faults to each diagnostic method. Finally conclude the type of fault exist by mapping of all faults to common indication to each method. A feasible GUI conferred to give visual display of five methods. The result of this method shows overall DGA accuracy is more than 90% compared to 80% of most reliable individual method.

Chapter 7: Deals with the general conclusions of the work done followed by future scope and references.

Chapter 2

GAS FORMATION IN MINERAL OIL

Overview:

This chapter mainly describes about literature review of TCG, GBA, DGA methods for gases identification. This chapter also describes total possible faults produced in mineral oil due to thermal and electrical degradation. Finally this chapter ends with block diagram representation of DGA combine design technique.

2.1 Literature Review

2.1.1 Total Combustible Gases (TCG)

It is the first method proposed to detect the fault gases, the major advantage of this method is “it will detect fault gases very quickly compare to other methods and it is applicable to use in the field” [10]. But it has number of disadvantages

1. It can detect only combustible gases like (carbon monoxide, hydrogen, acetylene, methane and ethylene) and does not indicate non-combustible gases like (carbon dioxide, oxygen and nitrogen) [3].
2. This method is applicable only those have gas blankets and does not completely oil filled units of conservator type.
3. The most disadvantage of TCG is it can give only one concentration value of incipient fault and also not clearly identify which gases are actually present.

2.1.2 Gas Blanket Analysis (GBA)

During this method, the sample of the gas in the space above the oil is analyzed for its finding the incipient faults [16]. It can detect all of the individual components like C-H bonds and C-O bonds. However it suffers following disadvantage.

- ✓ The gases must be diffuses into the gas blanket only
- ✓ it is not suitable for field

2.1.3 Dissolved Gas Analysis (DGA)

It is the useful informative method for the detection of incipient faults and most used method now a day. DGA involves following steps [3].

1. Sample of the oil taken from the unit and extract the dissolved gases from oil.
2. Detect the gas concentrations and analyse by diagnostic methods (Key Gas and Ratio analysis methods) to find faults.

It is applicable to all type high voltage equipment like the gas blanket analysis method and it can detect all the combustible and non-combustible gases. The following are the advantages of DGA [14].

1. Advance warning of developing of faults.
2. Status check on new and aged mineral oil.

3. Convenient online scheduling of repairs.
4. Identifies degradation level before it leads to failure.
5. Monitoring of units under overload case.
6. Checking the improper use of units.

The main advantage of DGA method is “it gives early identification of incipient faults”.

2.2 DGA Block Diagram

The steps involved in DGA is shown in following Figure 2.1

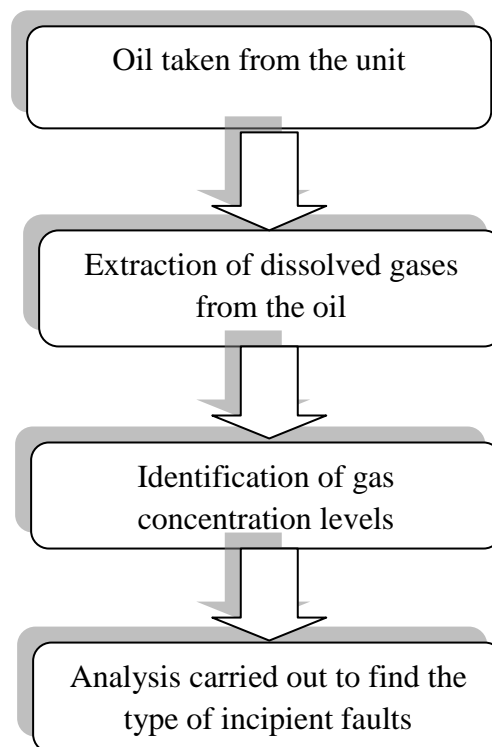


Figure 2.1: Flow Chart of DGA

Dissolved Gas Analysis (DGA) is a proved accuracy method to find faults. DGA mainly involves extracting or stripping of oil from the unit and subject to Gas Chromatography to extract the dissolved gases from oil [6]. The next step of DGA is detection of gas concentration levels using suitable methods like Flame Ionization detector, Thermal conduction detector (FID, TCD) and analyze for faults by using suitable diagnostic methods to find cause. Figure 2.1 indicates the entire process of DGA [2]. In this work, the condition based diagnosis system developed to combine five DGA assessment classical techniques-Key Gas Method, IEC Ratio Method, Rogers Ratio Method, Doernenburg Ratio Method and Duval Triangle Method. A feasible MATLAB GUI conferred to give visual display of all five

methods at one window and this result gives cause to incipient faults, which kind of fault exist by individual method and finally compare all five methods to find exact incipient fault by taking their percentage. The result of this method shows overall DGA accuracy is more than 90% compared to 80% of most reliable individual method [7]. DGA helps to diagnosis the present condition of the high voltage power transformer. 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 two type of thermal faults and low energy discharge type faults by taking key gases, Ratio methods gives high thermal, partial discharge and arcing but not giving combination of thermal and electrical faults [10]. In case of Duval triangle method, it gives almost all possible faults except faults temperature $<150^{\circ}\text{C}$, if these low temperature faults are not corrected may be it leads to high temperature faults in future and perhaps increase to arcing also and these causes high damage to transformer. 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. 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.

2.3 Gas Formation in Mineral Oil

The main cause for gas formation in mineral oil is cellulose and oil decomposition. When this degradation is occurred gases are produced like Carbon Oxides and Hydrocarbon Molecules.

I. Cellulose Decomposition

The thermal degradation of cellulose mainly produced carbon oxides (CO , CO_2) and hydrogen or methane (H_2 , CH_4) [2]. Due to thermal degradation in oil, carbon dioxide produced. The rate at which they are developed depends exponentially on the temperature and directly on the concentration of material at that temperature [11].

II. Oil decomposition

Mineral transformer oils are combination of hydrocarbon molecules and its general formulae is $\text{C}_n\text{H}_{2n+2}$, where n in the reach of 20 to 40. The deterioration forms for these hydrocarbons in thermal or electrical faults are more complex. The main reason

for generating the fault gases are breaking of carbon hydrogen and carbon-carbon bonds. These free radicals can mix with each other to form gases like hydrogen (H_2), methane (CH_4) and ethane (C_2H_6). Further decomposition in mineral oil develops such as ethylene (C_2H_4) and acetylene (C_2H_2) [12].

2.4 Interpretation of Gas Analysis

The main two causes of gas formation within an operating transformer are electrical and thermal degradations.

I. Thermal Faults

The decomposition of mineral oil from $150^\circ C$ to $500^\circ C$ generates low molecular weight gases, such as methane (CH_4), hydrogen (H_2) and low quantity of higher molecular weight gases like ethane (C_2H_6), ethylene (C_2H_4) [18]. If decomposition of mineral oil increases more than $500^\circ C$ generates large quantity of acetylene (C_2H_2). In case of thermal decomposition of paper insulation and other solid insulation produces carbon dioxide (CO_2), carbon monoxide (CO) [11].

II. Electrical faults

Two type of electrical faults are considered

1. Corona (or) Partial Discharge
2. Arcing (High Energy Discharge)

These faults mainly depend on intensity of energy dissipated per unit time per unit volume by the fault. Among all faults, most severe fault is arcing by developing acetylene and less severity fault is corona by producing large quantity of Hydrogen and Methane but if less severity fault was not correct, it leads to Arcing [14].

1. Corona (or) Partial Discharge

- a. Partial Discharge means “The dielectric breakdown of some part of solid (or) liquid when impressed by high voltage”. Here when the mineral oil of transformer is stressed by high voltage leads to production of several gases, discharges of cold plasma, bubbles (or) voids and with possible formation of X-wax in paper [12].
- b. The approximate percentage of gases among all dissolved gases when partial discharge occurs is $H_2=85\%-90\%$, $CO_2=1\%-2\%$, $CO=0.5\%-1\%$, $CH_4=6\%-10\%$, $C_2H_6=6\%-8\%$ and very low quantities of ethylene and acetylene. Hence,

during partial discharge occurred in oil leads to develop H₂ gas and in cellulose is produce carbon oxides including H₂.

2. *Arcing*

- a. Arcing in generally means “the electrical breakdown of a gas that developing ongoing plasma discharges, resulting current through normally non-conductive medium such as air” [18]. But in case of transformer severe energy dissipation occurs during arcing and it produces gases in the percentages approximately H₂=35%-40%, C₂H₂=35%-50% and remaining gases in very low volume.
- b. In any fault associated with paper, produce gases like CO₂ and CO in very large quantity approximately 85%-90%.

Chapter 3

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 and software development to MATLAB GUI program.

3.1 Block Diagram of DGA Combine Method

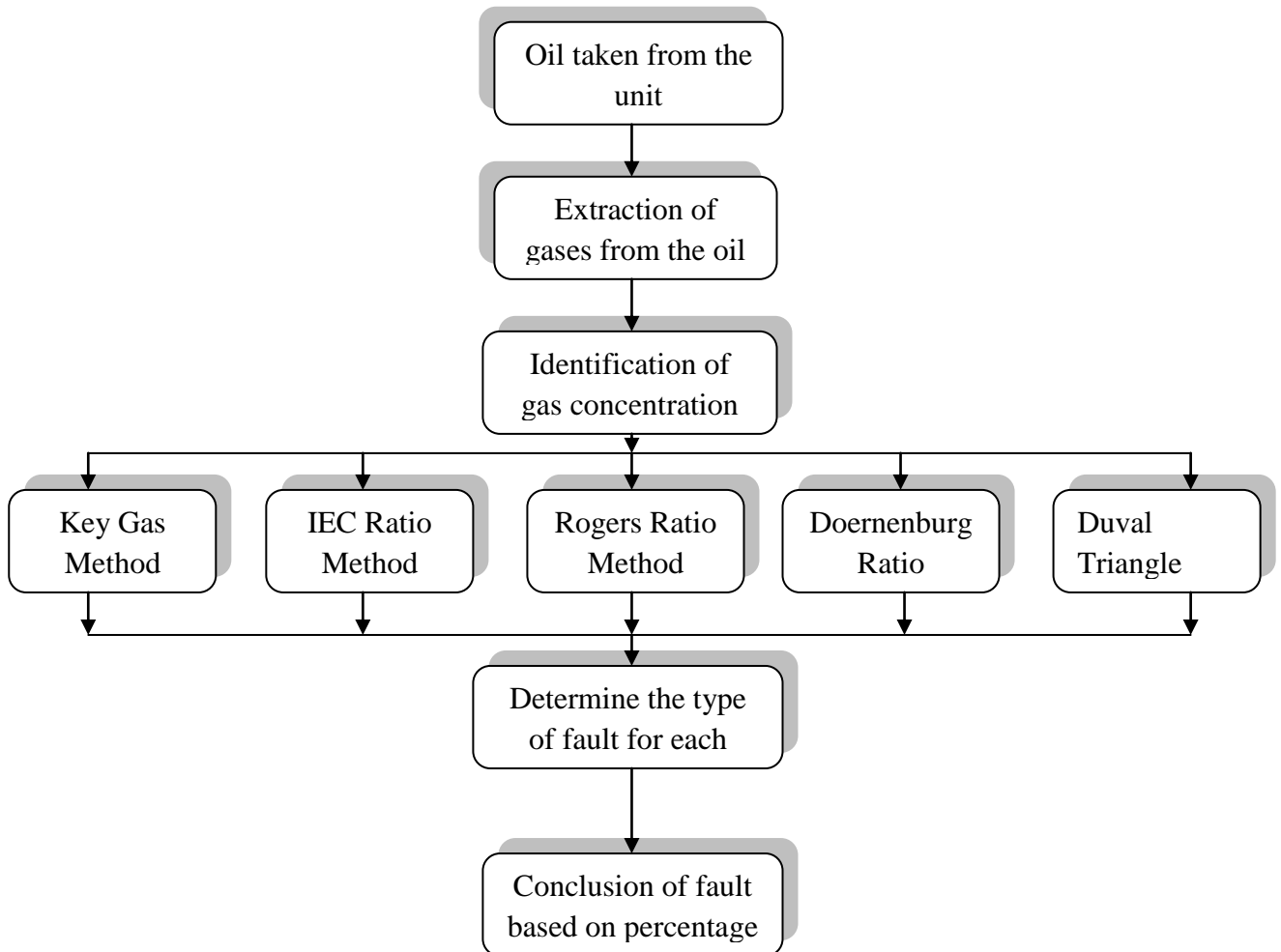


Figure 3.1: Block diagram of Combined Dissolved Gas Analysis (DGA) Method

Figure 3.1 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 $<150^{\circ}\text{C}$, 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.

3.2 Key Gas Method

The key gas method is mainly depends on the quantity of fault gases release in mineral oil when fault occur. Figure 3.2 to Figure 3.5 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].

3.2.1 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 produced
- ✓ The main Key gas exists when thermal faults occurred is ethylene (C_2H_4).

Figure 3.2 shows approximate relative proportions (%) for each fault gas.

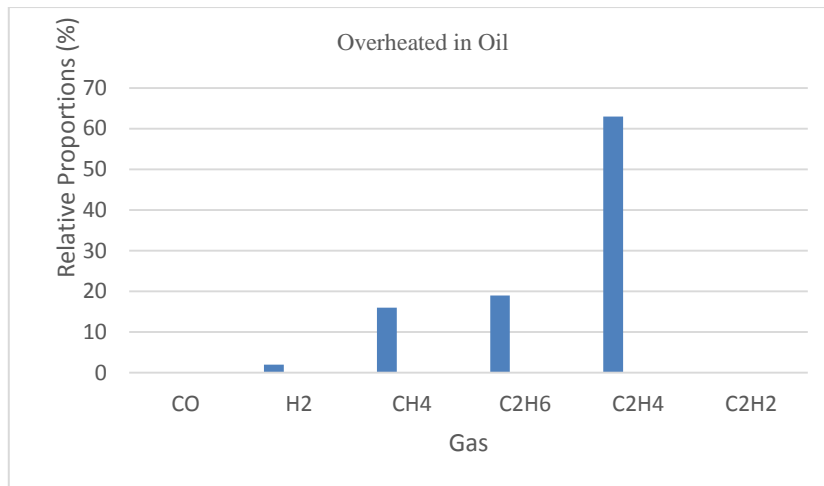


Figure 3.2 Approximate percentage (%) of gases found during thermal faults in oil inside the Transformer

ii. *Thermal Faults in Cellulose*

- ✓ It produced large quantity of carbon monoxide and carbon dioxide
- ✓ The main key gas is carbon monoxide (CO).
- ✓ Figure 3.3 shows approximate relative proportions (%) for each fault gas. In this case CO Produce more than 90%.

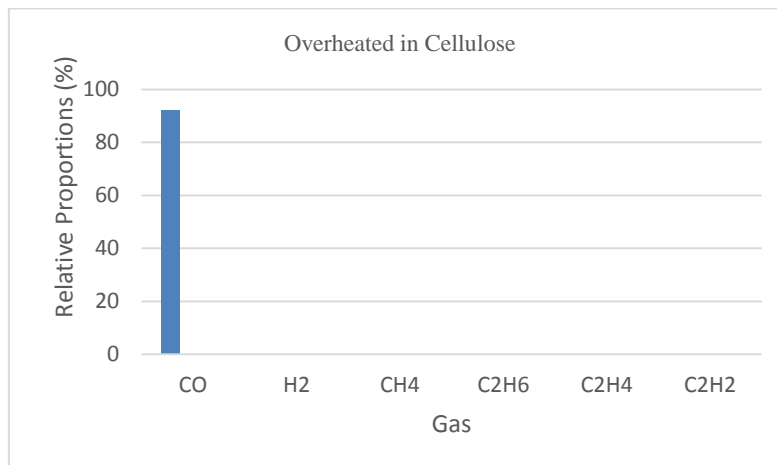


Figure 3.3: Approximate percentage (%) of gases found during thermal faults in Cellulose inside the Transformer

3.3.2 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 3.4 shows approximate relative proportions (%) for each fault gas in corona.

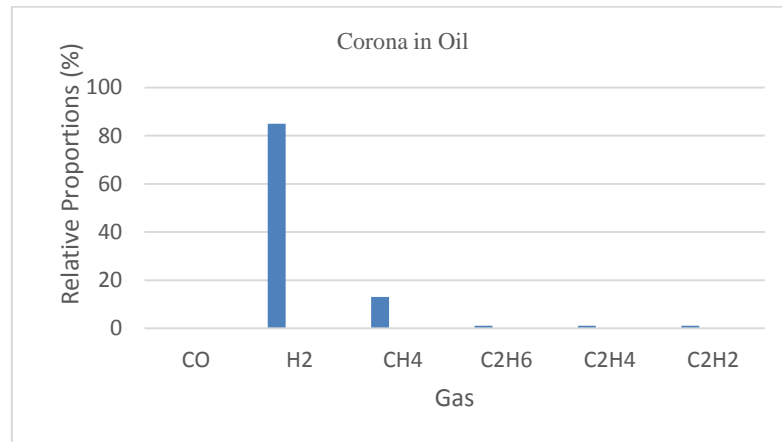


Figure 3.4: Approximate percentage (%) of gases found during Corona in oil inside the Transformer

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 3.5 shows approximate relative proportions (%) for each fault gas in arcing.

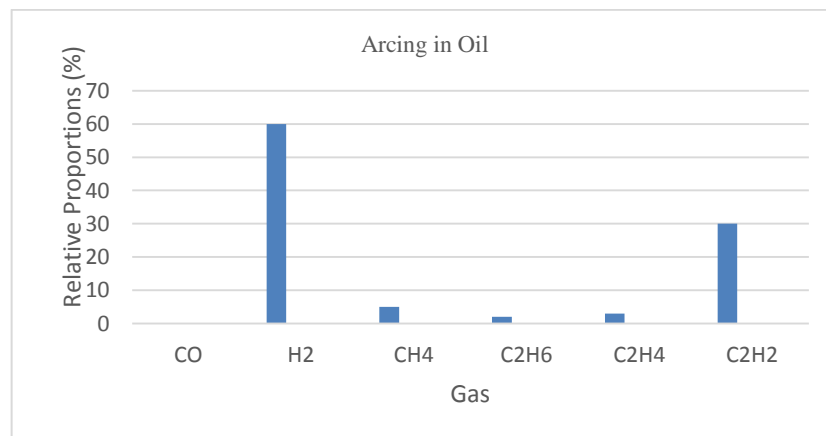


Figure 3.5: Approximate percentage (%) of gases found during Arcing in oil inside the Transformer

Figure 3.6 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 3.2

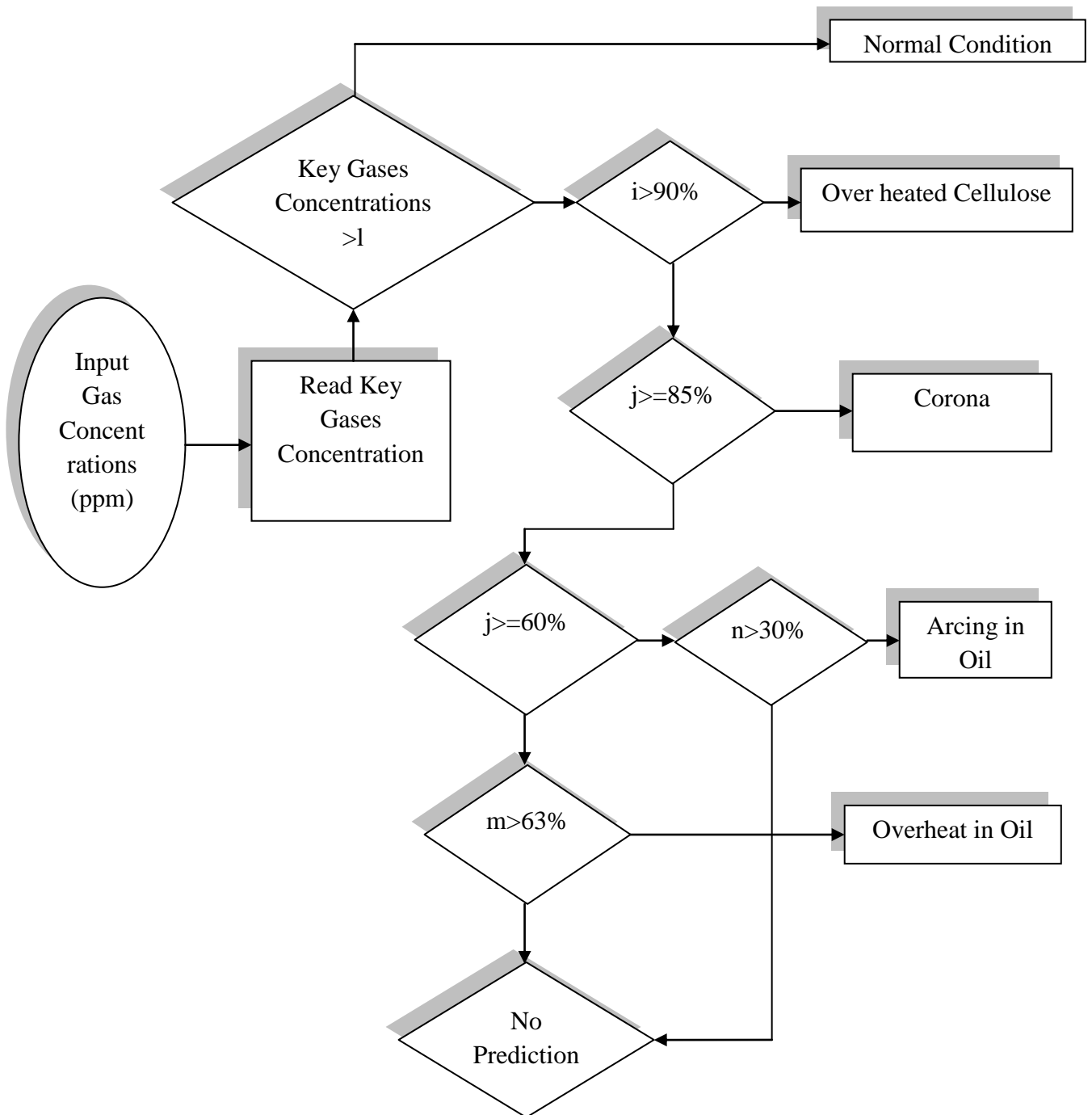


Figure 3.6: Flow Chart of Identification of gases present in Transformer oil using Key Gas Method

3.4 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 3.2, it represents fault exist otherwise shows normal condition. Figure 3.6 represents total steps involved to develop MATLAB GUI software.

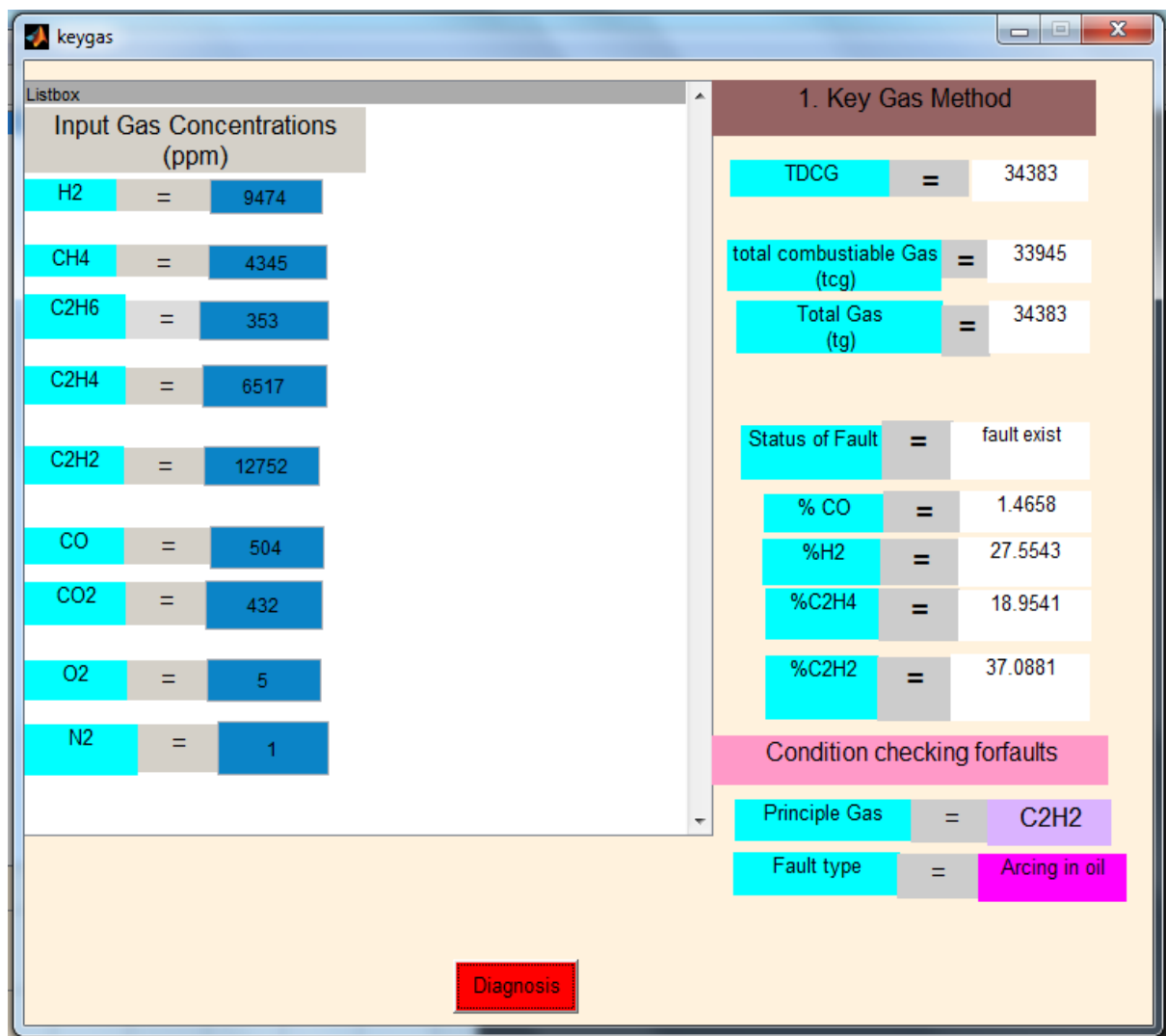


Figure 3.7: Result window of Key Gas Method using MATLAB GUI

3.5 Result and Discussions

Figure 3.7 indicates the GUI result for key gas method and for instance, gas concentrations taken as input (ppm) shown in Table 3.1

TABLE 3.1 INPUT GASES AND CONCENTRATIONS IN PPM

Input gas	H ₂	CH ₄	C ₂ H ₆	C ₂ H ₄	C ₂ H 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 non combustible gas CO₂. The GUI result in Figure 3.7 given status of the fault as “fault exist”, it means one of the key gas concentrations volumes is more than Table 3.2.

TABLE 3.2: LIMITATIONS OF KEY GAS METHOD [16]

Key Gas	Gas Concentration (ppm)
H ₂	150
CO	500
C ₂ H ₄	20
C ₂ H 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 C₂H₂ as 37.088%. It shows the given sample unit produced acetylene gas more than 30% due to arcing in oil.

Chapter 4

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.

4.1 Rogers Ratio method

4.1.1 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].

4.1.2 Diagnosis Codes Representation

Table 4.1 indicates gas ratios uses in Roger’s ratio method and their ratio code representation used in MATLAB GUI program.

TABLE 4.1: 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 4.1, as IEEE Standard C57.104-1991 gives more information to find exact faults [9]. Table 4.2 indicates the gas ratio codes for Rogers’s ratio method and it indicates type of faults occurred. Table 4.2 shows gas ratios range and codes in 0-5, codes used in Table 4.2 is only the software implementation purpose of Rogers ratio method and by using gas ratios range in Table 4.2, different faults conditions are developed. If any fault gases ratio range is beyond ratios shown in Table 4.2, this method is unable to find Incipient faults status and shows Rogers ratio method is not valid.

TABLE 4.2: 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 ₂ H ₆ /CH ₄)	<1.0	0
	>=1.0	1
k (C ₂ H ₄ /C ₂ H ₆)	<=1.0	0
	>=1.0,<3.0	1
	>=3.0	2
l(C ₂ H ₂ /C ₂ H ₄)	<0.5	0
	>=0.5,3.0	1
	>=3.0	2

By using Table 4.2 gas ratio ranges, developed 12 cases of possible diagnosis incipient faults in mineral oil. Table 4.3 indicates total possible cases of faults diagnosis by Rogers’s ratio method and their gas ratio ranges and codes representation for each case.

TABLE 4.3: TOTAL POSSIBLE DIAGNOSIS FAULTS FOR ROGERS RATIO METHOD

SL.NO	i (CH ₄ /H ₂)	j(C ₂ H ₆ /CH ₄)	k(C ₂ H ₄ /C ₂ H ₆)	l(C ₂ H ₂ /C ₂ H 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 ⁰ c)
4	1-2	1(>=1.0)	0	0	Overheating(150 ⁰ c-200 ⁰ c)
5	0	1	0	0	Overheating(200 ⁰ c-300 ⁰ c)
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 ⁰ c-700 ⁰ c)
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

4.1.3 Rogers Ratio Method Software implementation to MATLAB GUI

Hence by using Table 4.3 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 4.1 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.

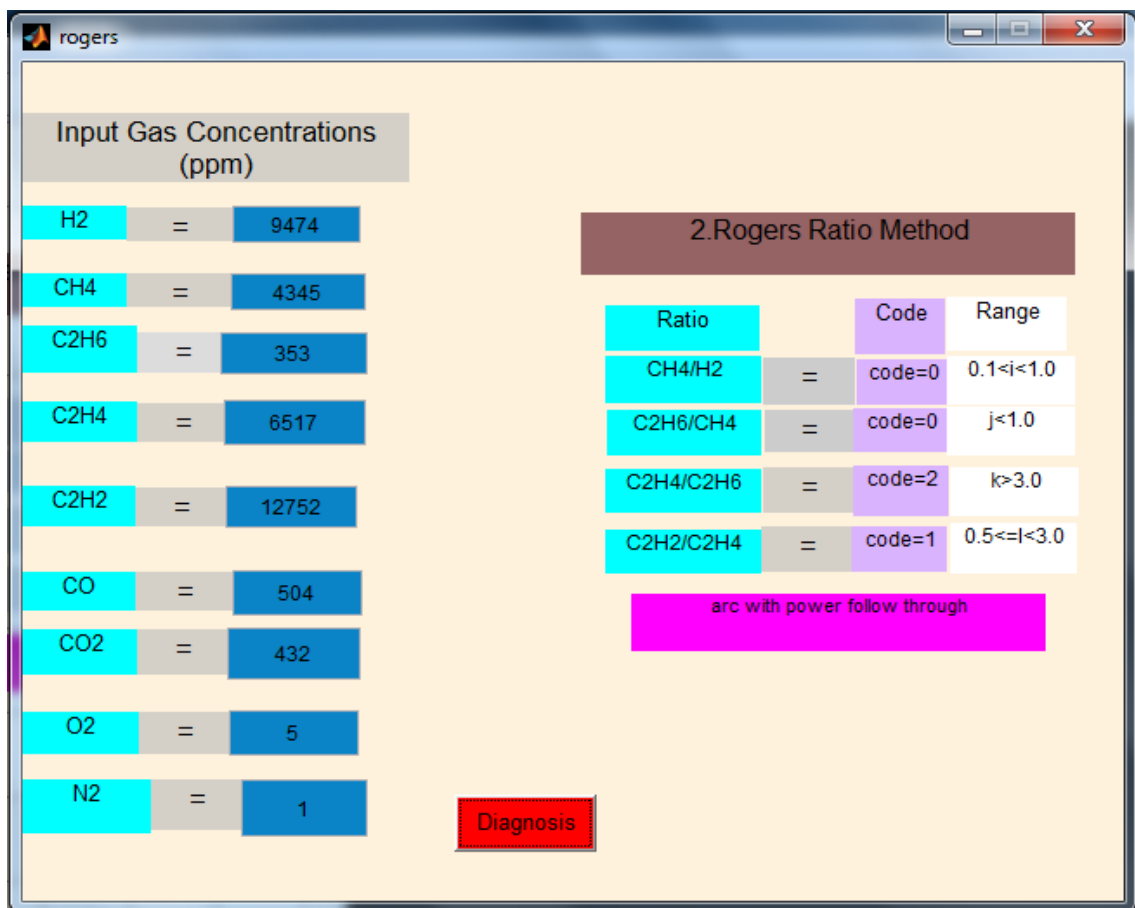


Figure 4.1 Result window of Rogers Ratio Method using MATLAB GUI

4.1.4 Result and Discussions

By taking the same sample input data used in key gas method shown in Table 3.1, Rogers's ratio method diagnosis the condition as "arc with power follow through". Figure 4.1 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 4.1 are

CH_4/H_2 gases ratio range is $0.1 < i < 1$ and corresponding code representation as code=0

$\text{C}_2\text{H}_6/\text{CH}_4$ gases ratio range is $j < 1.0$ and corresponding code representation as code=0

$\text{C}_2\text{H}_4/\text{C}_2\text{H}_6$ gases ratio range is $k > 3.0$ and corresponding code representation as code=2

$\text{C}_2\text{H}_2/\text{C}_2\text{H}_4$ gases ratio range is $0.5 \leq l < 3.0$ and corresponding code representation as code=1

Hence finally it given fault condition as "Arc with power follow through"

Manually also verified the this result by seeing the all gas ratios ranges and code displayed in Table 4.3, it also shows fault condition for corresponding codes show in Figure 4.1 as "arc with power follow through".

4.2 IEC Ratio Analysis

4.2.1 Introduction

IEC stands International Electro Technical Commission. It is also similar to Rogers ratio method expect one ratio dropped is $\text{C}_2\text{H}_6/\text{CH}_4$. 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].

4.2.2 Diagnosis Codes Representation

It is taking similar ratios of Rogers's ratio method except $\text{C}_2\text{H}_6/\text{CH}_4$; 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 are different compare to Roger's ratio method [6]. Table 4.4 indicates ratio codes, gas ratio ranges in ppm and their code representation to MATLAB GUI program [3].

TABLE 4.4: IEC RATIO CODE REPRESENTATION

Ratio code	Range	Code
l(C ₂ H ₂ /C ₂ H ₄)	<0.1	0
	0.1-3.0	1
	>3.0	2
i (CH ₄ /H ₂)	<0.1	1
	0.1-1.0	0
	>1.0	2
k(C ₂ H ₄ /C ₂ H ₆)	<1.0	0
	1.0-3.0	1
	>3.0	2

Hence by using Table 4.4 gas ratio ranges, developed eight cases of fault conditions such as shown in Table 4.5 and this Table 4.5 indicates entire type of faults for corresponding code ranges of gas ratios.

TABLE 4.5: TOTAL POSSIBLE DIAGNOSIS FAULTS FOR IEC RATIO METHOD

SL.NO	l(C ₂ H ₂ /C ₂ H ₄)	i(CH ₄ /H ₂)	k(C ₂ H ₄ /C ₂ H 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 ⁰ c-300 ⁰ c)
8	0	2	1	Thermal fault(300 ⁰ c-700 ⁰ c)
9	0	2	2	Thermal fault(>700 ⁰ c)

4.2.3 IEC Ratio Method Software implementation to MATLAB GUI

Figure 4.2 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 4.3 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.

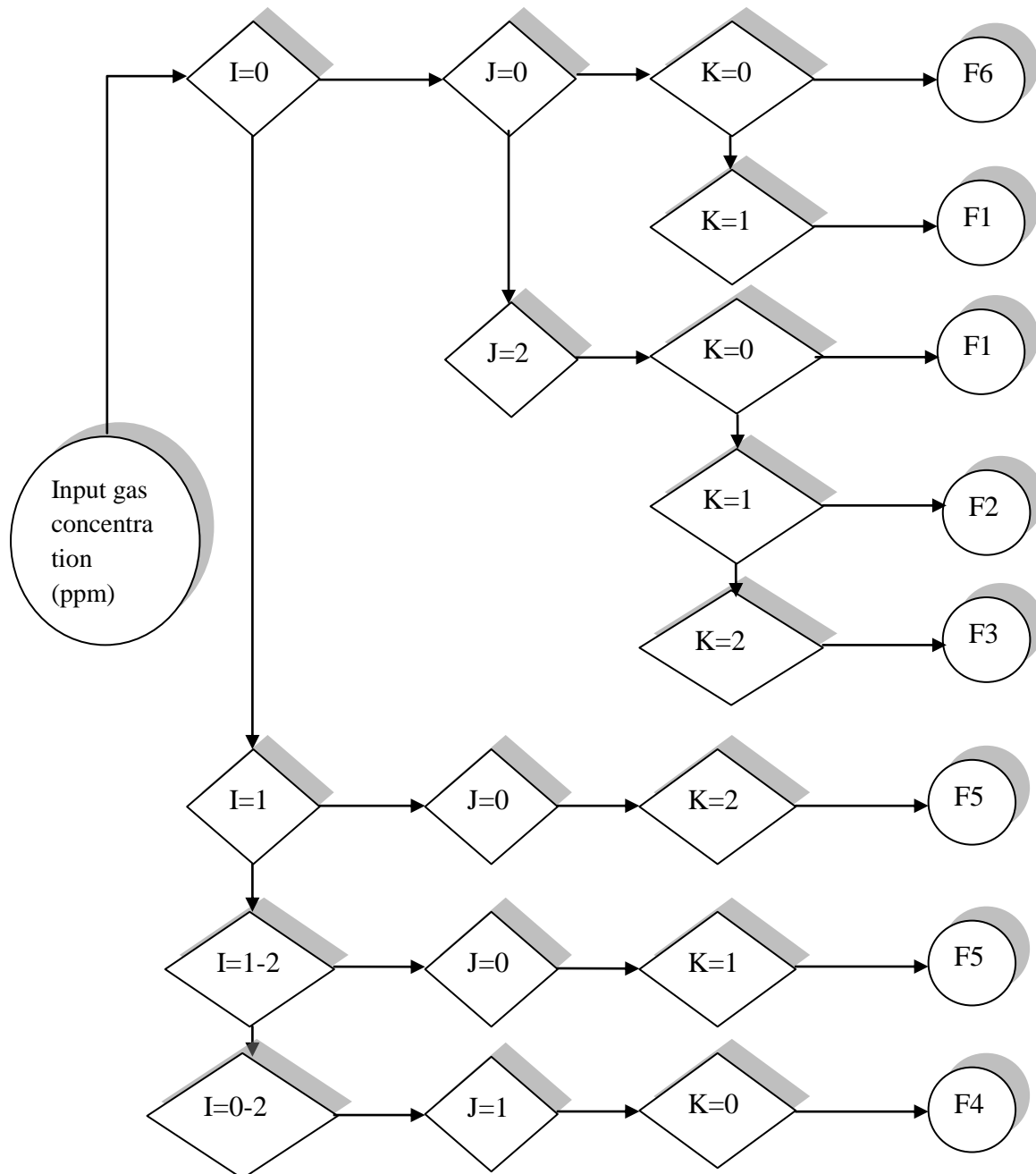


Figure 4.2: Flow Chart of Identification of gases present in Transformer oil using IEC Ratio Method



Figure 4.3 Result window of IEC Ratio Method using MATLAB GUI

4.2.4 Result and Discussions

By taking the same sample input data used in key gas method shown in Table 3.1, IEC ratio method diagnosis the condition as “No Prediction” means IEC method fails to diagnosis the fault condition. Figure 4.3 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 4.1 are

C_2H_2/C_2H_4 gases ratio range is $0.1 < i < 3.0$ 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 4.5, it also shows same fault condition for corresponding codes show in Figure 4.1 as not valid.

4.3 Doernenburg Ratio Method

4.3.1 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 C_2H_2/C_2H_4 . Taking these gas ratios ranges, it diagnosis the different fault conditions like partial discharge, arcing and thermal faults in various degree of severity [9]. Table 4.6 indicates the minimum level of gas concentrations for key gases used in this method [11].

TABLE 4.6: 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 4.7: RATIOS FOR KEY GASES IN DOERNENBURG METHOD [6]

Suggest Fault Diagnosis	P(CH ₄ /H ₂)	Q(C ₂ H ₂ /C ₂ H ₄)	R(C ₂ H ₆ /C ₂ H ₂)	S(C ₂ H ₂ /CH ₄)				
Thermal	>1.0	<0.75	<1.0	<0.3	<0.1	>0.4	>0.2	
Decomposition	>0.1							
Corona (low intensity PD)	<0.1	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 4.7 indicates the total possible diagnosis faults by taking gases ratios ranges such as Thermal Decomposition, Corona (low intensity PD) and Arcing (High intensity PD).

4.3.2 Doernenburg Ratio Software implementation to MATLAB GUI

4.3.2.1 Step by step procedure

- Step 1:** Collect sample unit and extract the dissolved gases and find the gas concentrations by using Gas Chromatograph.
- Step 2:** If at least one of the gas concentrations (in ppm) overcomes twice the values for Limits (see in Table 4.6) and one of the other three gases exceeds the values for limits shown in Table 4.6, 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 4.7 (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 4.7 in the order P, Q, R, and S. If all succeeding ratios for a specific fault type fall within the values given in Table 4.7, the suggested diagnosis are valid [11]. Hence this entire process represent in flow chart show in Figure 4.4.

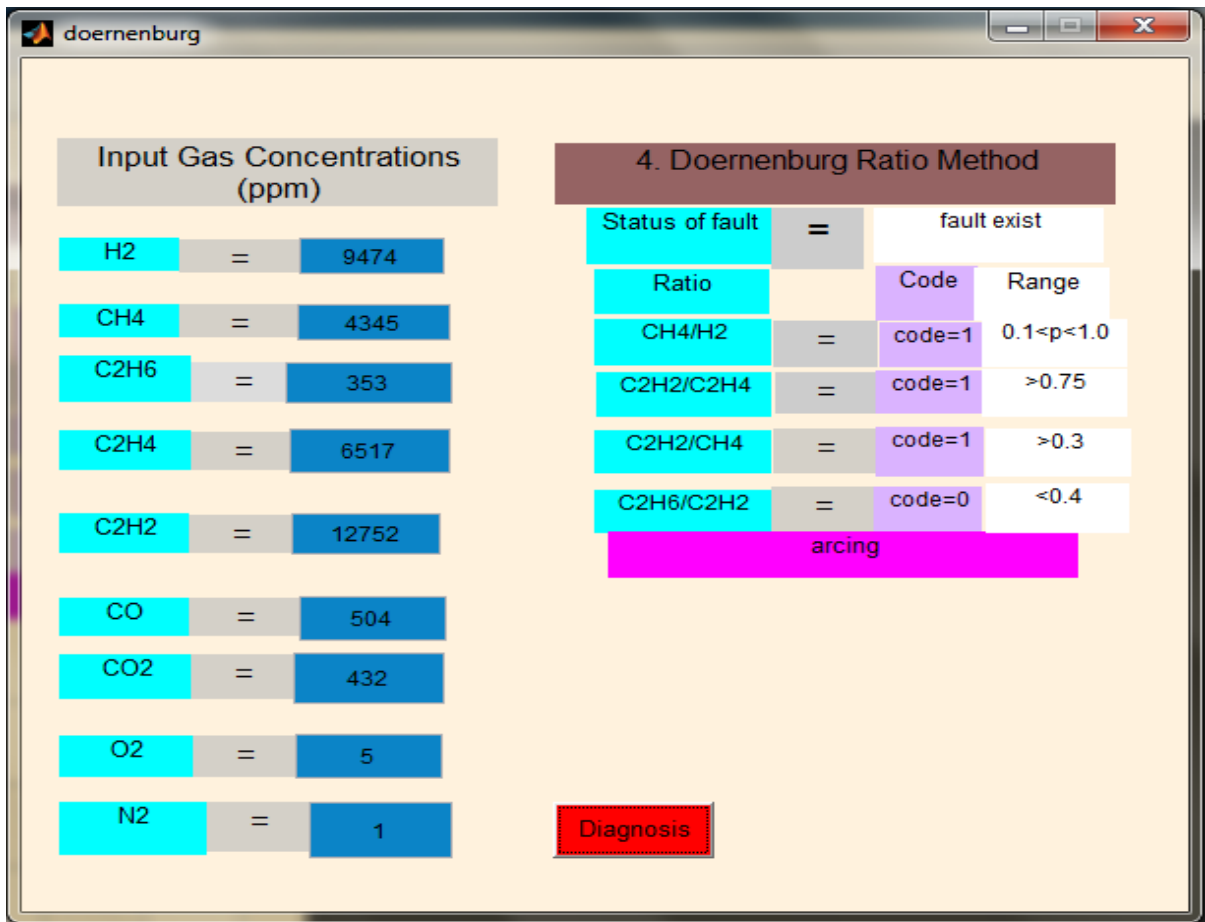


Figure 4.5: Result window of Doernenburg Ratio Method using MATLAB GUI

4.3.2.2 Result and discussions

By taking the same sample input data used in key gas method shown in Table 3.1, Doernenburg ratio method diagnosis the fault condition as “Arcing”. Figure 4.5 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 4.5 are

CH₄/H₂ gases ratio range is 0.1<P<1 and corresponding code representation as code=1

C₂H₂/C₂H₄ gases ratio range is Q>0.7 and corresponding code representation as code=1

C₂H₂/CH₄ gases ratio range is R<0.3 and corresponding code representation as code=1

C₂H₆/C₂H₂ 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 4.7, it also shows fault condition for corresponding codes show in Figure 4.5 as “Arcing”.

Chapter 5

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

5.1 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 5.1 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 categorised into seven zones like D1, D2, T1, T2, T3, PD and DT shown in Table 5.1. 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 Figure 5.5. The three sides of triangle mentioned in Figure 5.1 are $\% \text{CH}_4$, $\% \text{C}_2\text{H}_4$, and $\% \text{C}_2\text{H}_2$ and these values should be within 0 to 100% for each gas [5].

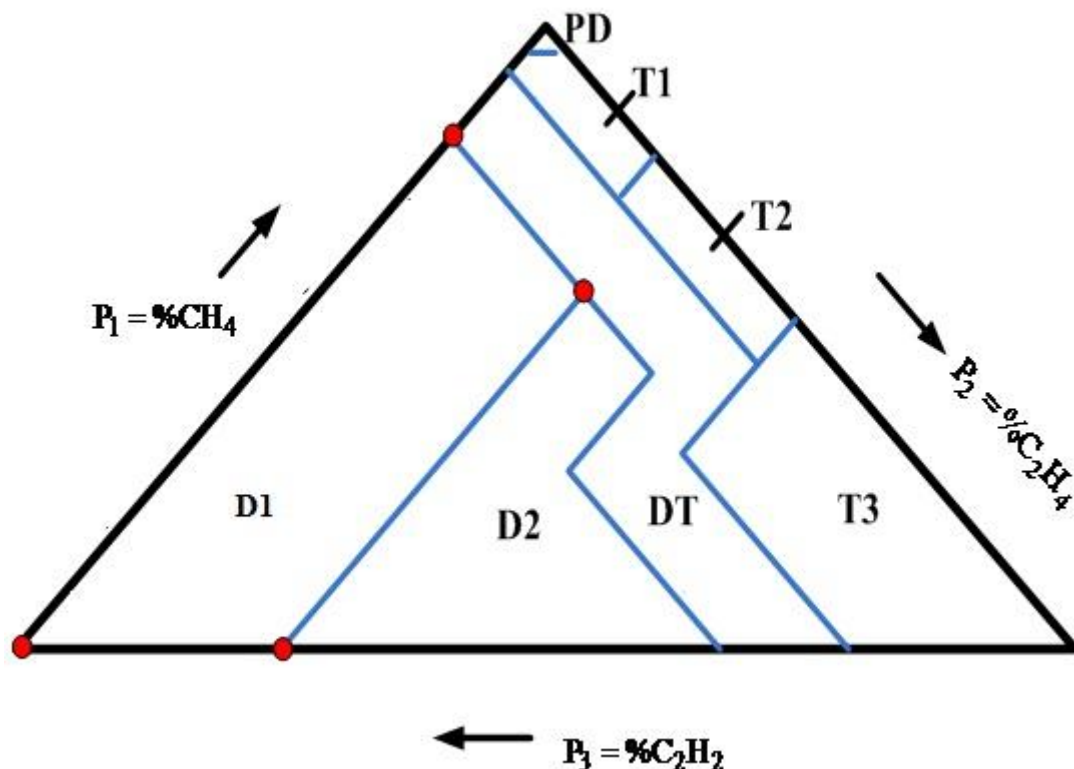


Figure 5.1: Duval Triangle Method representation of three types of fault zones

TABLE 5.1: 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 ⁰ C-700 ⁰ C	formation of carbon particles, Carbonization of paper
DT	Combination of Electrical and Thermal	Discharges of low energy, pinholes

5.2 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 $\text{CH}_4=60$, $\text{C}_2\text{H}_4=120$ and $\text{C}_2\text{H}_2=20$

$$P_1 = \% \text{CH}_4 = 30\%$$

$$P_2 = \% \text{C}_2\text{H}_4 = 60\%$$

$$P_3 = \% \text{C}_2\text{H}_2 = 10\%$$

From a percentage of P_1 (such as point D) draw a parallel line to BC, from percentage of P_2 (such as E) draw a parallel line to CA and from a percentage of P_3 (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 5.2 shows sample of point shown in a triangle for above example of gases concentrations.

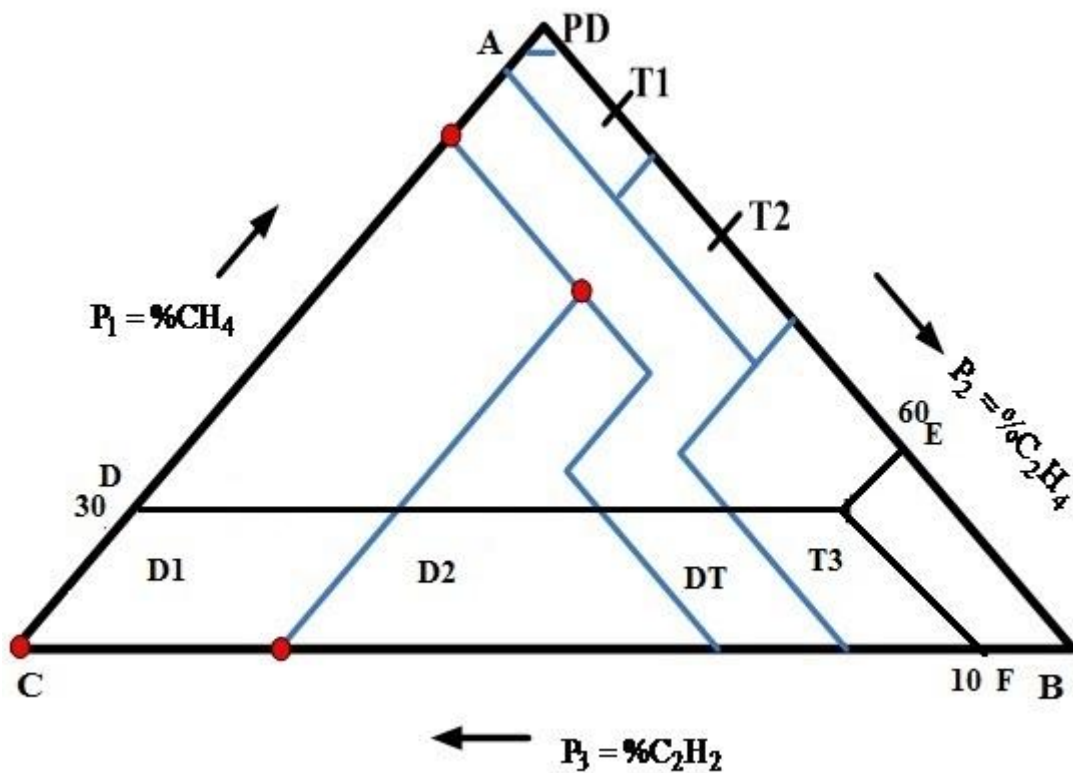


Figure 5.2: Sample of fault zone point showed in a Duval Triangle Method

5.3 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 5.3, 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 P_1 , P_2 and P_3 . Figure 5.3 shows all points of every polygon of Duval triangle. Sometimes one point is common for neighbouring polygons e.g. points D_{12} and D_{21} of polygons D_1 and D_2 are the same, Table 5.2

shows Duval triangle coordinates for seven zones of Duval Triangle. To characterize each polygon, the points shown in Table 5.2 should be changed over to Cartesian coordinates utilizing trigonometric properties to represent Duval Triangle in MATLAB.

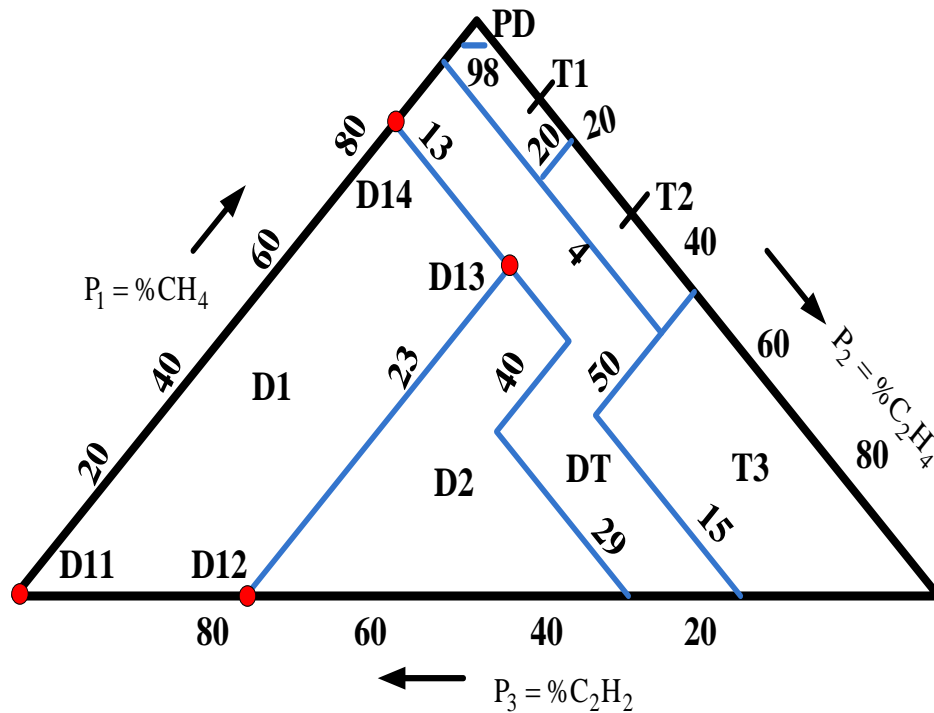


Figure 5.3: Different fault zone coordinates representation of Duval Triangle

Table 5.2 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 (%CH₄, %C₂H₄ and %C₂H₂).

TABLE 5.2: DUVAL TRIANGLE TRIANGULAR COORDINATES [8]

Area	Points	%CH ₄	%C ₂ H ₄	%C ₂ H 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

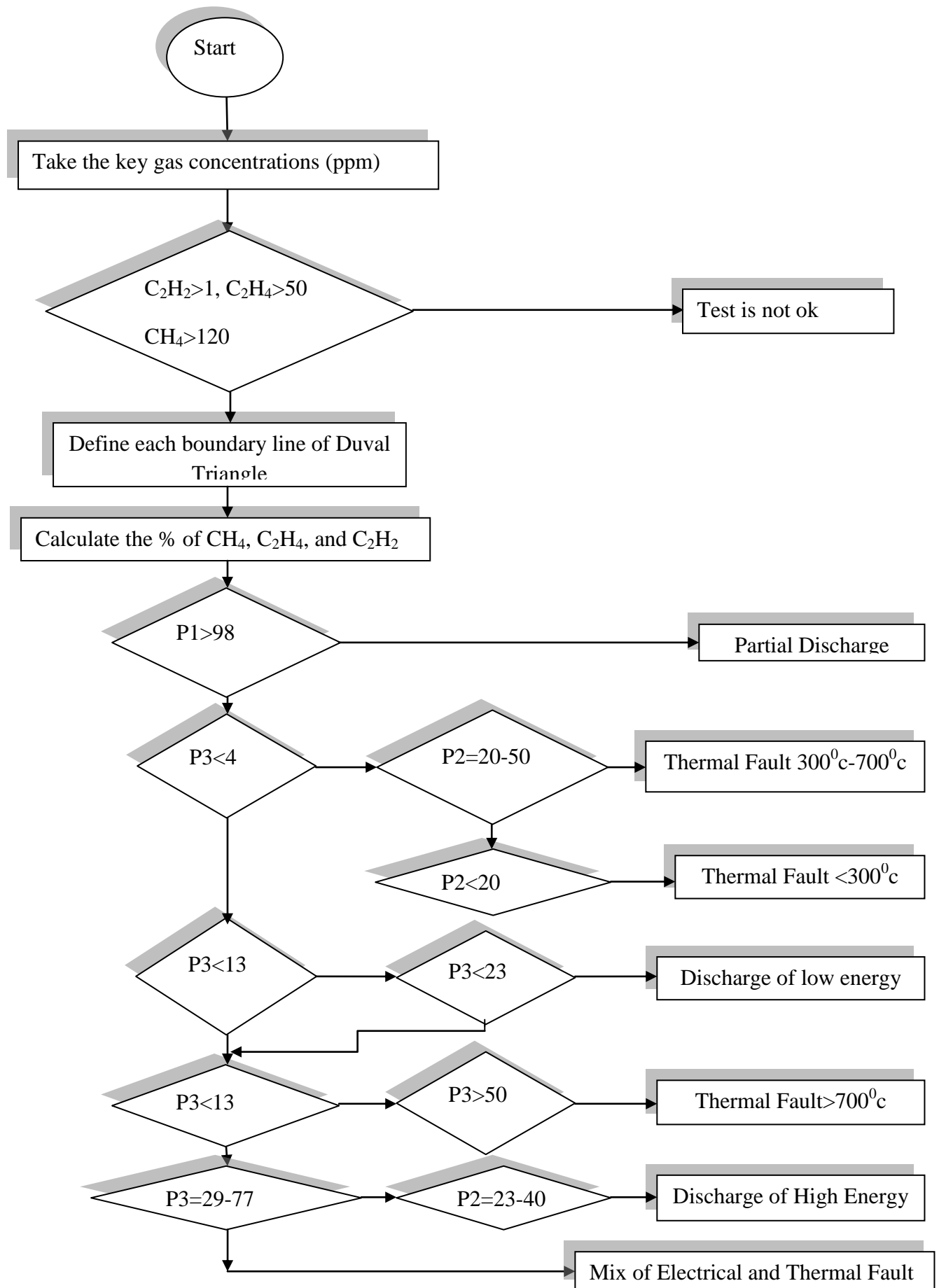


Figure 5.4 Flow chart of Identification of % CH₄, %C₂H₄ and %C₂H₂ gases present in Transformer oil using Duval Triangle Method

5.4 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 5.4 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 5.4. If it is ok then only it forwards to next steps and diagnosis the faults otherwise simply it shows “Test is not ok”.

5.5 Result and Discussions

By taking the same sample input data used in key gas method shown in Table 3.1, Duval Triangle Method gives result in shown in Figure 5.5

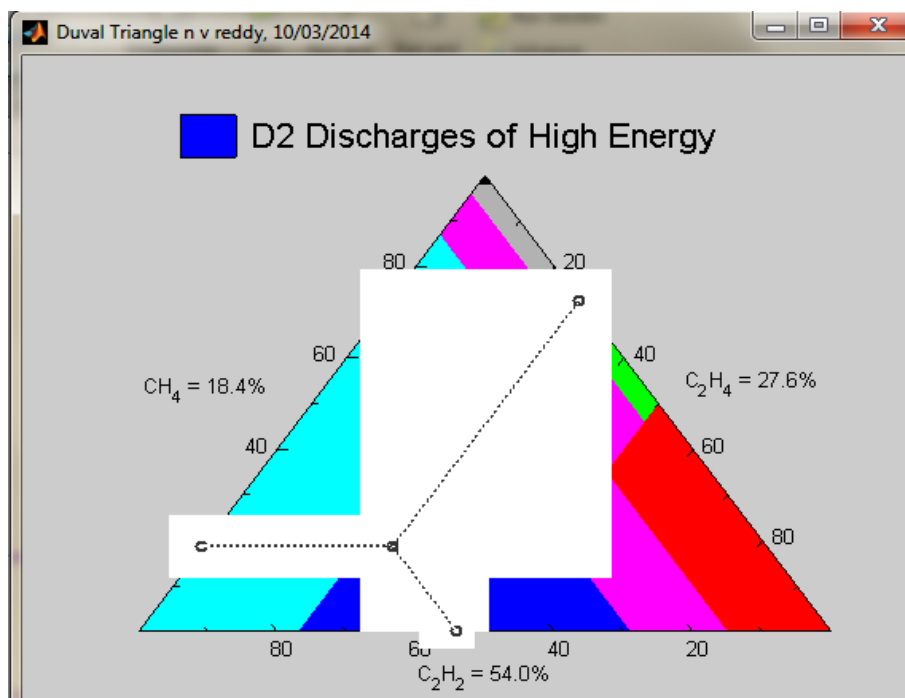


Figure 5.5: Result window of Duval Triangle Method using MATLAB GUI

Figure 5.5 represents the Duval Triangle result for gas concentrations shown in Table 3.1 and it shows the key gases concentrations as %CH₄=18.4, %C₂H₄=27.6 and %C₂H₂=54. Hence it diagnosis the fault condition as “Discharge of High Energy”.

Chapter 6

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.

6.1 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 “Aging 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 categorised into seven types of faults and these faults assign with a fault codes F1-F7 shown in Table 6.1

TABLE 6.1: TOTAL INCIPIENT FAULTS CATEGORIZED IN TRANSFORMER OIL

SL.NO	Fault Type	Code
1	Thermal faults <300 ⁰ C	F1
2	Thermal faults 300 ⁰ C-700 ⁰ C	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 6.2 indicates the mapping process of all individual method faults to 7 seven types of faults and those are indicated as F1-F7.

TABLE 6.2: 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 ₂ H ₄	No prediction	Principal gas H ₂	Principal gas C ₂ H 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

6.2 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°C - 700°C), 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.

6.3 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.

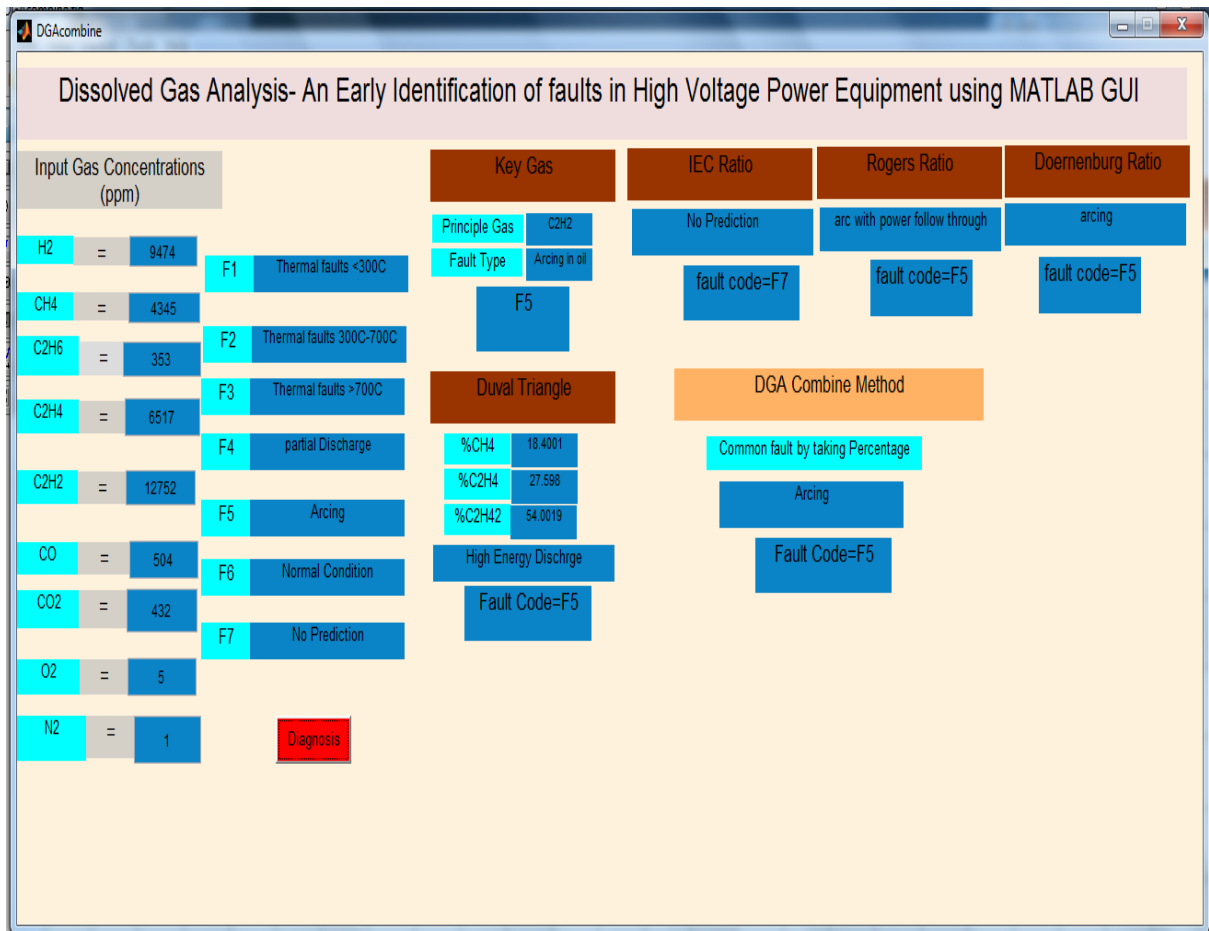


Figure 6.1: Result window- Identification of incipient faults of Transformer oil by comparing five diagnosis Methods

6.4 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 6.1 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 6.3 indicates sample input data and table 6.4 indicates the type of faults diagnosis by all 30 cases for each individual method and combined DGA method. Figure 6.1 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 3.1, Combine DGA Method given results shown in Figure 6.1. 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 6.2. 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 6.2. Duval Triangle method diagnosis the result as “Discharge of High Energy” and it is mapped with fault code F5 see in table 6.2. 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 3.1, 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 analyse and precautions can take to avoid failure of transformer. In the sense life period of transformer and reliability is increased.

TABLE 6.3: SAMPLE INPUT DATA [18]

SL.NO	H ₂ (ppm)	CH ₄ (ppm)	C ₂ H ₆ (ppm)	C ₂ H ₄ (ppm)	C ₂ H ₂ (ppm)	CO (ppm)	CO ₂ (ppm)	N ₂ (ppm)	O ₂ (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 6.4: DIAGNOSIS OF FAULTS BY ALL INDIVIDUAL AND COMBINE DGA METHODS

SL.NO	Key Gas	IEC Ratio	Rogers Ratio	Doernenburg Ratio	Duval Triangle	Combine 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 6.3 indicates the sample input data and Table 6.4 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 6.5: COMPARING THE PERCENTAGE PREDICTION OF INDIVIDUAL AND DGA COMBINE METHODS

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 6.4. Table 6.5 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 7

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.

7.1 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 analyse and precautions can take to avoid failure of transformer. In the sense life period of power transformer and reliability has been increased.

7.2 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.

References

- [1] Ena Narang, Er Shivanisehgal, “Fault Detection Techniques for Maintenance Using Dissolved gas Analysis”, International Journal of Engineering Research & Technology (IJERT), Vol. 1 Issue 6, pp. 01-07 August – 2012.
- [2] Lelekakis. N, Martin. D, Wenyu Guo, Wijaya. J, “Comparison of dissolved gas-in-oil analysis methods using a dissolved gas-in-oil standard”, Electrical Insulation Magazine, IEEE , vol.27, no.5, pp.29,35, September-October 2011
- [3] AbubakarA. Suleiman1, Ali S. Alghamdi, “Improving accuracy of DGA interpretation of oil-filled power transformers needed for effective condition monitoring”, 2012 IEEE International Conference on Condition Monitoring and Diagnosis 23-27 September 2012, Bali, Indonesia.

- [4] Sukhbir Singh, Dheeraj Joshi and M.N. Bandyopadhyay, "Software Implementation of Duval Triangle Technique for DGA in Power Transformers", International Journal of Electrical Engineering, Vol. 4, No. 5, pp. 529-540, 2011.
- [5] Sukhbir Singh and M.N. Bandyopadhyay, "Duval Triangle: A Noble Technique for DGA in Power Transformers", International Journal of Electrical and Power Engineering, Vol. 4, Issue-3, pp.193-197, 2010.
- [6] Sherif S. M.Ghoneim, IEEE Member, Sayed A. Ward, "Dissolved gas Analysis an Early Identification of Transformer Faults", Advances in Electrical Engineering Systems (AEES), Vol. 1, No. 3, 2012, ISSN 2167-633X
- [7] Rahul Pandey, M.T. Deshpande, "Dissolved Gas Analysis (DGA) of Mineral Oil used in Transformer", IJAIEEM, Volume 1, Issue 2, October 2012.
- [8] A. Akbari, A. Setayeshmehr, H. Borsi, E. Gockenbach, "A Software Implementation of the Duval Triangle Method", IEEE International Symposium on Electrical Insulation, Vol. 6, No. 8, pp. 124-127, 2008.
- [9] Andri Febriyanto, Tapan Kumar Saha, "Oil-immersed Power Transformers Condition Diagnosis with Limited Dissolved Gas Analysis (DGA) Data", Australasian Universities Power Engineering Conference (AUPEC), pp-073, 2008.
- [10] Lynn Hamrick, "Dissolved Gas Analysis for Transformers", Neta World, pp. 01-04, 2009- 2010.
- [11] ANSI/IEEE Std C57.104-1991, "IEEE Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers", IEEE Power Engineering Society, 1992
- [12] Joseph B. DiGiorgio, "Dissolved gas Analysis of Mineral Oil Insulating Fluids", 2013 NTT
- [13] Lynn Hamrick, "Dissolved Gas Analysis for Power Transformer", NETA WORLD Winter 2009-2010.
- [14] N.A. Mahamad, B.T. Phung and T.R. Blackburn, "Comparative Study and Analysis of DGA Methods for Transformer Mineral Oil", 2010 IEEE International Conference on Condition Monitoring and Diagnosis 20-25 October 2010.
- [15] A. Akbari, A. Setayeshmehr, H.Borsi, E.Gockenbach, "A software Implementation of The Duval Triangle Method", Leibniz Universitat Hannover, Callinstr. 25 A, 30167 Hannover, Germany.
- [16] Sam J. Ferrito, "A Comparative Study of Dissolved Gas Analysis Techniques: The Vacuum Extraction Method versus the Direct Injection Method", IEEE Transactions on Power Delivery, Vol.5, No.1, pp. 220-225, 1990.

- [17] Sayed A. Ward, "Evaluating Transformer Condition Using DGA Oil Analysis", annual Report Conference on Electrical Insulation and Dielectric Phenomena, 2003.
- [18] DVSS. Sivasarma, GNS.Kalyani, "Ann approach for Condition Monitoring of Power Transformers using DGA", IEEE Electrical Insulation Magazine. 2002. p. 12-25.
- [19] IEC Publication 60599, "Mineral Oil-Impregnated Equipment in Service – Guide to the Interpretation of Dissolved and Free Gases Analysis", March 1999.
- [20] Adam Junid, Simin Li, Lingfeng Ni, " Dissolved Gas Analysis and its Interpretation techniques for Power Transformer", October 21, 2008.