Exploring Possibility to Enhance DGA Interpretation Accuracy for EHV/UHV Power Transformer

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DEPARTMENT OF ELECTRICAL ENGINEERING

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Exploring Possibility to Enhance DGA Interpretation Accuracy for EHV/UHV Power Transformer

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Submitted in partial fulfillment of the requirements

For the degree of

Master of Technology in Electrical Power Systems

By

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MAY 2014

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This is to certify that the Major Project Report entitled " Exploring possibility to enhance DGA interpretation accuracy for EHV/UHV Power transformer " submitted by R Praneeth (12MEEE24), towards the partial fulfillment of the requirements for the degree of Master of Technology(Electrical Engineering) in (Electrical Power Systems) of Nirma University, Ahmedabad is the record of work carried out by him under my supervision and guidance. In my opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this Seminar, to the best of my knowledge, haven't been submitted to any other university or institution for award of any degree or diploma.

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Abstract

Power transformers play a vital role in power transmission and distribution system. Modern high voltage transformers to keep their size in acceptable range are built with relatively tight insulation tolerances compared to older equipment and are consequently subjected to increasingly high stresses in service. It is therefore very important to closely monitor their in-service behavior to avoid incipient faults, catastrophic failures, costly outages and losses of production.

Dissolved gas analysis of transformer oil is used to asses the insulation condition by periodic sampling the oil samples and measuring amounts of gases dissolved in oil by gas chromatography. Different types of interpretation of DGA data is analyzed to and the root cause of production of the gases, the accurate method is considered for predictive measures to be taken depending on gas concentration and rate of increase of levels of gas.The gas concentration levels in oil is effected by so many factors and they play an important role in the DGA based diagnosis process. Rate of rise of gas level can be considered as a factor for determination of cause of failure but other factors that are associated with it are stray gassing and change in solubility of the gas in oil. A mathematical approach is then proposed in the areas of stray gassing and change in solubility that is helpful for removal of the bad data from the preprocessing stage of the DGA data interpretation there by increasing accuracy of the interpretation.

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With immense pleasure, I would like to present this report on the dissertation work related to ”Exploring possibility to enhance DGA interpretation accuracy for EHV/UHV Power transformer” . I am very thankful to all those who helped me for the successful completion of the dissertation and for providing valuable guidance throughout the project work.

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Chapter 1

Introduction

1.1 Background

Power transformer plays a complex and vital role in power system transmission and distribution. Recently there is an increase in power demand hence for transmission of high power from generation to load there has been increase in demand of extra high voltage (EHV) and Ultra high voltage transformer(UHV). These transformers are subjected to various stress when they are in service condition and they have high manufacturing and maintenance cost. Hence to avoid undesired failures and outage these transformers are expected to work in healthy condition and to ensure this a continuous condition monitoring of transformer done. DGA is one of the tools for condition monitoring of oil of power transformers. This report throws a light on application of DGA as an efficient tool to asses the insulation condition and also to improve transformer service life.

1.2 Literature Survey

The first and most important part of any studies is to understand the underlying concepts and the importance of the topic.This is achieved by survey of wide literature available. This section describes about some important papers read to understand the concept of dissolved gas analysis (DGA) of transformer oil and interpretation techniques.

1.2.1 Michael Duval [1][2][3]

Modern high voltage transformers to keep their size in acceptable range are built with relatively tight insulation tolerances compared to older equipment and are consequently subjected to increasingly high stresses in service, manufacturing cost and maintenance cost is very high. It is therefore very important to closely monitor their in-service behavior to avoid catastrophic failures, costly outages and losses of production [1]. Emphasis of using DGA as a very efficient tool for this purpose is done, the operating principle is explained as follows the slight harmless deterioration of the insulation that accompanies incipient faults, in the form of arcs or sparks resulting from dielectric breakdown of weak or overstressed parts of the insulation, or hot spots due to abnormally high current densities in conductors [1]. The process of obtaining the dissolved gases is explained, the main gases evaluated from DGA are CH_4,H_2, C_2H_6, C_2H_4, C_2H_2, CO and CO_2. From the data of volume of the gases evolved in PPM Duval triangle plot is plotted. Acceptable range of gases concentration in oil is studied and compared with other standards[1]. In 2002 to improve the accuracy of interpretation of data of DGA using Dual triangle , based IEC publication 60599 some modification in plotting the triangle are discussed [2]. The extensive study is made on effects caused in evolution of gases by on load tap changer (OLTC) [2]. Case studies are made using modified Duval triangle interpretation and accuracy of the method is compared with standards [2]. There are recommendations in IEC and CIGRE for the use of 90 % of typical values of gas concentrations and rate of gas rise by 2007, by this individual network are encouraged to calculate their own typical values, since they may vary depending upon the operating conditions. Paper [3] proposes methods for calculating these individual gas limits and sampling intervals, based on the recommendations and observations published by CIGRE and the IEC. Below 90 % of typical values, where little or no gas formation is observed, it is considered that transformers are operating normally and average range for these changed values of each gas is calculated in PPM and rate of rise PPM/ day. Methods are specified for the individual transformer user to calculate their own DGA limits and sampling function as a part of function of the gas concentration and rate of increase in service [3].

1.2.2 Tapan K. Saha[4][5]

A number of electrical, chemical and mechanical techniques for assessing the insulation of the aged transformer is investigated [1]. Effectiveness of each technique is studied and results are obtained. From the results obtained a comparative analysis is made between the techniques, merits and demerits of each technique are discussed [4]. DGA and its interpretation is discussed, the most effective interpretation of DGA data is studied. New techniques that are used for monitoring the insulation level is discussed [5].

1.2.3 Joseph J. Kelly[6]

Decomposition of oil and oil-impregnated equipments insulation under the influence of the electrical and thermal stress is discussed. The gases evolved in the due to decomposition product that are dissolved in the oil are obtained using gas chromatography. The main cause of liberation of gases is :

- There are three primary causes of fault gases.
- The gases that are generated in the "reactor" are only a few.
- The gases are soluble in transformer oil.
- The fault's generating gases usually occur underneath the oil's surface.

The three primary faults that are cause of the gases liberation are :

1) Corona (partial discharge),

2) Thermal heating,

3) Arcing.

The different types of gases observed are in testing laboratory on the models are:

- **Overheating of Cellulose** : The cellulose is overheated and the gases collected, found that the primary products of this experiment are carbon monoxide and carbon dioxide.
- **Pyrolysis of Cellulose** : Over heating is done to decompose the cellulose. The decomposition products collected are water, carbon oxides, and carbon-acetous materials in the form of tar or coke.
- **Overheating Transformer Oil** : The insulating mineral oil, when overheated, will liberate hydrocarbon vapors, notably ethylene, ethane, and methane.
- **Oil Decomposition under Electrical Stress** : When a huge block of energy is released into the oil (such as an electric arc), large quantities of hydrogen and lesser amounts of acetylene will be collected with small volumes of light hydrocarbons.

The method that is used to understand the aging of insulation is :

(1) Gathering the data

(2) Interpreting the data:

Data obtained from the analysis of nearly 5000 transformers considers units ranging in size from 25 kVA-300 MVA, case study is made.

1.2.4 Amritpal Singh and P. Verma[7]

This paper focuses on the different intelligent methods which have led to the development of an expert system based on Dissolved Gas Analysis (DGA) for on-line condition monitoring of power transformers. The advantages of expert system and fuzzy logic approaches can take human expertise and DGA standards from the fault diagnosis system is discussed. By using artificial intelligence methods the rules can be generated automatically and the decisions would be made. Thefuzzy logic application is explained as follows fuzzy logic analysis involves three successive processes, namely: Fuzzification, Fuzzy Inference and Defuzzification. Fuzzification converts crisp data into a fuzzy input membership. A Fuzzy Inference System draws conclusions from the knowledge-based fuzzy rule set or if- then linguistic statements. Defuzzification then converts the fuzzy output back into crisp outputs. Here the crisp input are the codes depending on the ratio of CH_4/H_2, C_2H_4/CH_4,C_2H_4/C_2H6 and C_2H_2/C_2H_4. Combination of artificial intelligence and expert fuzzy system is done and Neuro-Fuzzy Based Expert systems is formed and DGA Data is fed to this system this systems and analysis is made.

1.2.5 R.R.Rogers [8]

In this paper author has employed a ratio techniques between the gases concentration that are dissolved in the transformer oil and are responsible for deterioration of oil insulation, the method and modification required to enable this technique for the fault interpretation from the DGA data is discussed. This technique is used as the code/ standard for the interpretation of faults from DGA Data very well knows Rogers ratio standards.

1.3 Problem Identification

Dissolved gas analysis of transformer oil is used as important tool to assess the Insulation condition of the transformer. The accuracy and correct predictive measures depends on the process of obtaining the data and interpreting it in correct way.The data that has obtained for the interpretation contains both good data and bad data. Existing methods of the interpretation are not reliable to use only good data for interpretation and remove the bad data ,so there is necessity to enhance the accuracy of the DGA interpretation.

1.4 Objective and Scope of Work

The objective of project work is to understand the different factors effecting the accuracy of DGA data interpretation. Extract the factors that are significantly effect the accuracy of the diagnosis process .A mathematical method is adapted for calculating the magnitude of this bad data and then to analyze the applicability of the results obtained to existing DGA data for enhancement of the DGA data interpretation.

Chapter 2

Transformer

A transformer is essentially a static electromagnetic device consisting of two or more windings which link with a common magnetic field. It works on the principle of electromagnetic induction. The main components are core, winding, insulation and tank. The purpose of the transformer core is to provide the low reluctance for the magnetic flux linking the primary and secondary windings. The primary and secondary winding are so arranged so as to reduce the leakage flux in the transformer. The core experiences iron loss due to hystersis and eddy current flow. Windings are most made from hard half drawn annealed copper. Multiple layer disc winding with shield winding is used in ehv transformer so that the impulse voltage is shared between the layers.

Transformer insulation is mainly provided mainly through mineral oil and kraft paper. The mineral oil is still used with better refining and selection. The tanks of transformer are made of welded plates. For cooling the transformer different methods are used depending on the capacity and requirement.

2.1 Insulating Materials

These are the materials which permit only a negligible current (order of pA) to flow in phase with the applied voltage.Examples are paper, cloth, paraffin .Inorganic insulation materials used are mica, ceramics and glass.Properties of insulating materials:

(1) High dielectric strength sustained at elevated temperature

(2) High resistivity

(3) Good thermal conductivity

(4) High tensile and shear strength

(5) High degree of thermal stability

2.1.1 Transformer oil:

Oil used for insulation in transformers is mineral oil and it is obtained by refining crude oil, animal oil and vegetable oils are not used for this purpose as these from fatty acids on heating which are corrosive for the cellulosic paper used in insulation three properties of that are fundamental to use of mineral oils as dielectric are :

- High insulating property.
- Good oxidative and ageing stability
- Good heating transfer.
- High electric strength to withstand the stresses in service.
- Sufficiently low viscosity so that its ability to circulate and transfer heat is not impaired
- High flash/fire points
- Good resistance to emulsion to prevent holding water
- Free from sludging under normal separating conditions.
- Low water content .

2.1.2 Paper insulation:

Insulation grade paper is made by the delignification of wood pulp by the kraft process.It contains about cellulose, ligin and, the balance is hemicellulose.The natural humidity of paper is 4-5 % by weight and thd with insulating oil is dried after winding to lessthan 0.05 % .The dried paper is impregnated with insulating oil, which increases its dielectric strength and also serves to cool the windings.The major constituent of paper is cellulose, which is natural polymer of glucose. Power transformer conductor windings are insulated by paper impregnated with insulating oil,which is expected to last the life of transformer(25 years minimum at an operating temperature of 65-95°c). In order to serve as a good insulant, paper should have following properties:

- Good breakdown voltage
- High resistivity
- Low dissipation factor
- Good tensile strength
- High degree of polymerization
- Low cost

2.2 Detoriation of insulation

Insulation degradation in aged transformer can be explained by the cause of chemical and electrical aspects.

2.2.1 Chemical aspects of deterioration of the transformer oil :

The production of hydrocarbons and permanent gases are mainly due to the ageing of transformer oil by thermo chemical reactions.With heat, moisture and O_2 in the environment, the ageing of oil results in the formation of soluble and insoluble products which accumulates in the transformer oil and deteriorate its property. This also effects the cellulose insulation of the winding of the transformer, there is no cure for the cellulose insulation degradation but oil can be reconditioned and re-claimed to its original specifications if the fault is detected in the early stages.

2.2.2 Electrical aspects of deterioration of transformer oil:

Insulation degradation occurs when the transformers are over stressed may be due to over load and over voltages. The electrical faults are as follows:

- Discharge resulting from incomplete impregnation or super saturation or cavitations or high humidity. This some times leads to tracking or perforations of solid insulation.
- Arcing .
- Insulated conductor overheating.
- Continuous sparking.
- Localized overheating of the core due to concentration of flux.
- Over heating of copper due to eddy currents, bad contacts or joints..

The problems arising from these gases are deterioration of dielectric properties of oil and lowering of its flash point from 145°c to the level around 50-60°c in extreme condition.

2.3 Condition monitoring and its benefits

Recently deregulation of the energy market and advances in science and technology, has posed so many constraints in transformer industry.The deregulation pressures are reflected in efforts for :

- Cost reduction, which is affecting maintainence, replacement, repair and upgarde philosophies.
- Increase power transformer availability, in order to assure power quality and customer satisfaction.
- Handling unprecedent power flow patterns in the system.

Consequences of the changing situations on the market have been a trend to allow higher overloads,to work power transformer longer and to take all additional measures to achieve it.These two facts imply that the transformer user accepts high risk of operation but at the same time a high availability is required.To solve above problems improved means of transformer life assessment and condition evaluation, monitoring and diagnosis is required.

Benefits of condition monitoring:

- On time proactive decision making
- Reducing unplanned outage
- More predictable and reliable maintenance schedules
- Reduced maintenance costs
- Timely filled measurements
- Confirmation, on spot, of the presence of the faults gases in the event of alarms
- The results provide the quality control feature,limiting the probability of destructive failures

Chapter 3

DGA data interpretation methods

3.1 Key Gases Method

In this method diagnoses result is based on determining the relative magnitude of the key gases to the other gases dissolved in transformer insulating oil. This method can only predict four general fault types shown in figures 3.1 and 3.2:

- **Hydrogen:** Large quantities associated with corona (partial discharge) conditions.
- **Hydrogen, Methane, Ethene, and Ethylene:** Results from thermal decomposition of oil.
- **Carbon Monoxide:** Produced by thermal aging of the paper.
- **Acetylene:** Associated with an electric arc in oil.

3.2 Rogers Ratio Method

The ratio methods may consist of single ratios of gases along with guidelines to evaluate different levels of normal, caution and warning. The ratio techniques can also compose of multiple ratios. These methods determine the transformer oil condition,

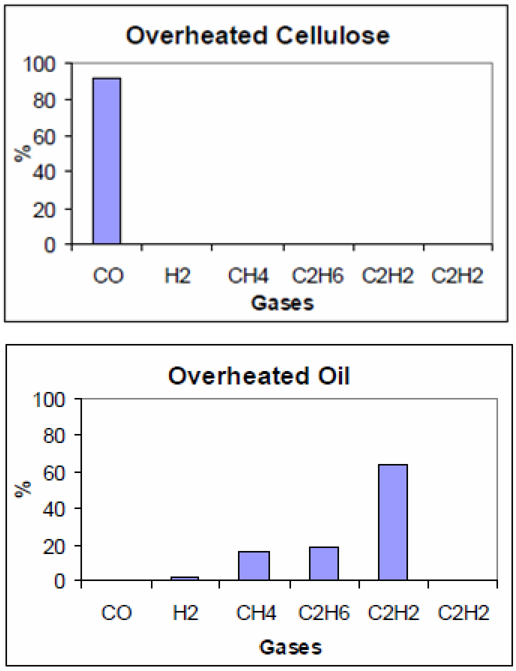

Figure 3.1: Key Gas Method

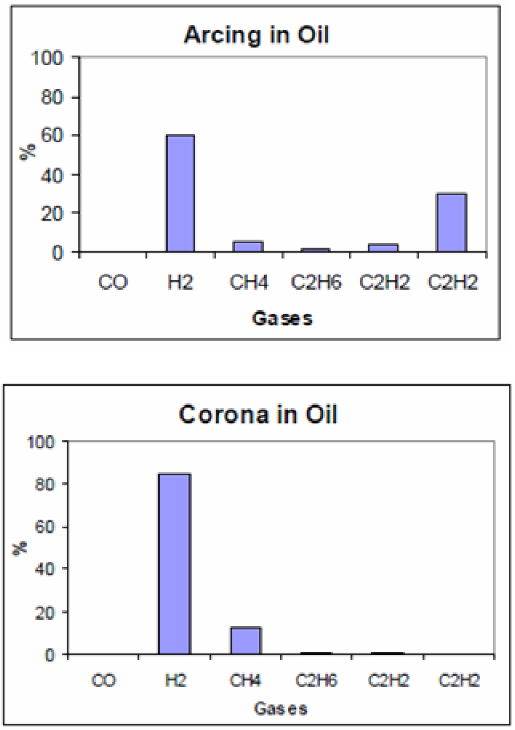

Figure 3.2: Key Gas Method

Table I: Rogers codes:

Code range of ratios	**C1** C_2H_2/C_2H_4	**C2** CH_4/H_2	**C3** C_2H_4/C_2H_6
less than 0.1	0	1	0
0.1-1	1	0	0
1-3	1	2	1
>3	2	2	2

by fitting the calculated ratios in specific range of value. A theoretical thermodynamic assessment of the formation of the simple decomposition gaseous hydrocarbons in mineral oil which suggested that on the basis of equilibrium pressures at various temperatures, the proportion of each gaseous hydrocarbon in comparison with each of the other hydrocarbon gases varied with the temperature of the point of decomposition explained in the fig 3.3. This led to the assumption that the rate of evolution of any particular gaseous hydrocarbon varied with temperature, and that at a particular temperature there would be a maximum rate of evolution of that gas and that each gas would attain its maximum rate at a different temperature. Hydrogen evolution is shown first, but this is represented initially by a large amount of hydrogen produced by ionic bombardment under discharge conditions (i.e. ”cold”), followed by a continual increase of hydrogen representing the increasing rudimentary fractionating of the long chain paraffin molecule under increasing temperature conditions. The above considerations led to the choice of ratios as explanied in the table I: for fault diagnosis,CH_4/H_2, C_2H_4/C_2H_6 and C_2H_2/C_2H_4 . The fault analysis can be done from the codes obatined using table III.

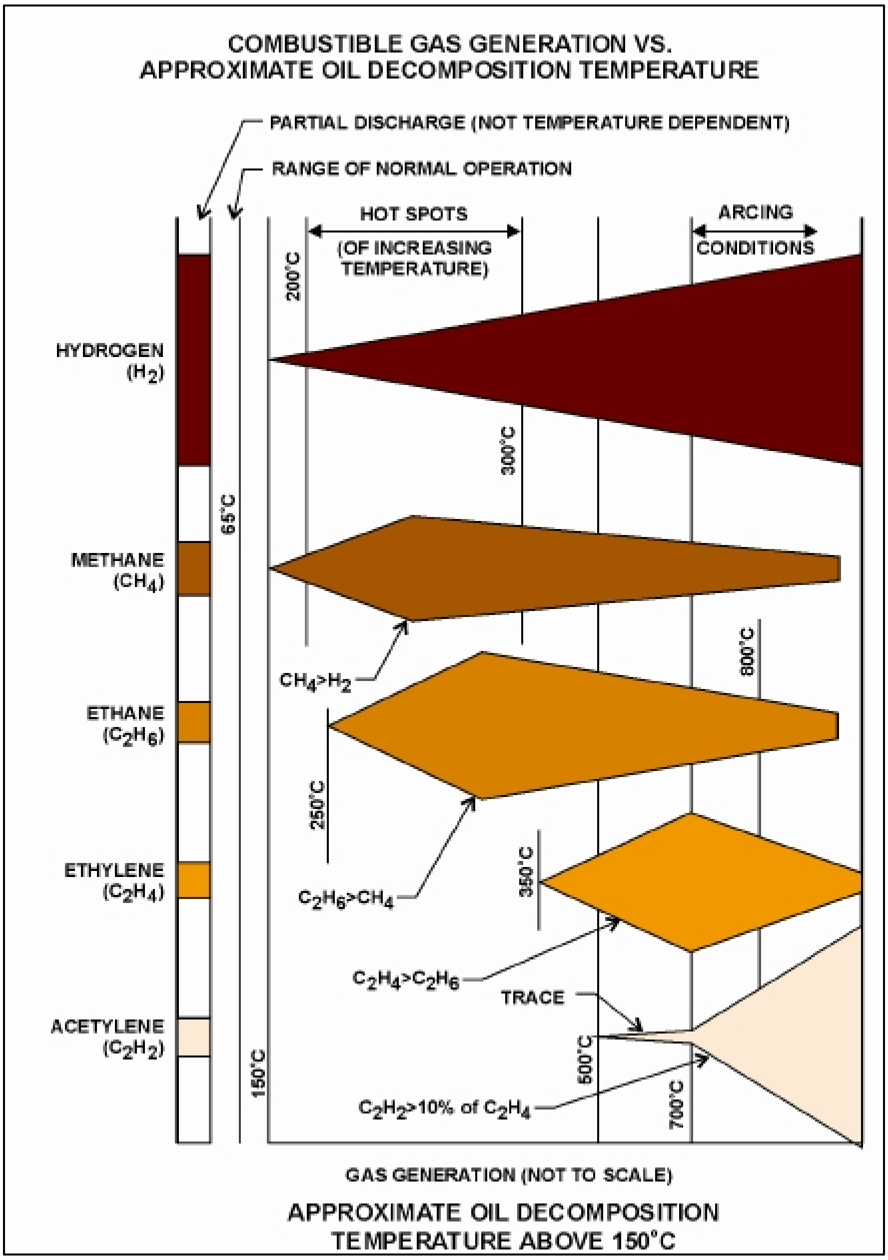

Figure 3.3: Comparative rate evolution of gases as a function of decomposition energy

Table II: Limit Concentration of dissolved gas:

key gas	**L1** H_2	**L2** CH_4	**L3** CO	**L4** C_2H_2	**L5** C_2H_4	**L6** C_2H_6
Concentrations(ppm)	100	120	350	1	50	65

Table III: Code analysis of gas dissolved in mineral oil

C	**Fault Type**	**C1**	**C2**	**C3**	**Typical examples of fault**
0	No fault	0	0	0	Normal aging
1	Low energy partial discharge	1	1	0	Electric discharges in bubbles, caused by insulation voids or super gas saturation in oil or cavitation (from pumps) or high moisture inoil (water vapor bubbles).
2	High energy partial discharge	1	1	0	Same as above but leading to tracking or perforation of solid cellulose insulation bysparking, or arcing; this generally produces CO and CO_2.
3	Low energy discharges,sparking, arcing	1-2	0	1 -2	Continuous sparking in oil between bad connections of different potential or to floating potential (poorly grounded shield, etc); breakdown of oil dielectric between solid insulation materials.
4	High energy discharges, arcing	1	0	1	Discharges (arcing) with power follow through; arcing breakdown of oil between windings or coils, between coils and ground, or load tap changer arcing across the contacts during switching with the oil leaking into the main tank.
5	Thermal fault T_1 less than 150°C	0	0	1	Insulated conductor overheating; this generally produces CO and CO_2 because this type of fault generally involves cellulose insulation.
6	T_2 (150°C to 300°C)	0	2	0	Spot overheating in the core due to flux concentrations.Items below are in order of increasing temperatures of hot spots: small hot spots in core; shorted laminations in core; overheating of copper conductor from eddy currents; bad connection on winding to incoming lead or bad contacts on load or no-load tap changer; circulating currents in corethis could be an extra core ground (circulating currents in the tank and core); this could also mean stray flux in the tank. These problems may involve cellulose insulation which will produce CO and CO_2.
7	T_3 (300°C to 700°C)	0	2	1	Same as above
8	Thermal fault >700°C	0	2	2	Same as above

3.3 Duval triangle

The process of obtaining the dissolved gases is explained, the main gases evaluated from DGA are H_2, CH_4, C_2H_2, C_2H_6, CO and CO_2. From the data of volume of the gases evolved in PPM Duval triangle plot is plotted in figure 3.4. In 2002 to improve the accuracy of interpretation of data of DGA using Dual triangle , based IEC publication 60599 some modification in plotting the triangle are done. The extensive study is made on effects caused in evolution of gases by on load tap changer (OLTC).

The extensive study is made on effects caused in evolution of gases by on load tap changer (OLTC). Paper [3] proposes methods for calculating these individual gas limits and sampling intervals, based on the recommendations and observations published by CIGRE and the IEC. Below typical values, where little or no gas formation is observed, it is considered that transformers are operating normally and average range for these changed values of each gas is calculated in ppm and rate of rise ppm/ day.

3.4 IEEE ratios/Dorenburgs ratio

In 1970, Dornenburg differentiated between faults of thermal or electrical origin by comparing pairs of gases with approximately equal solubility and diffusion coefficients such as ethylene and acetylene where an increase in the ratio of ethylene/acetylene above unity indicated an electrical fault, and also used the ratio of CH_4/H_2 to suggest an indication of a thermal fault if the ratio was greater than 0.1 or a corona discharge if the ratio was less than 0.1.

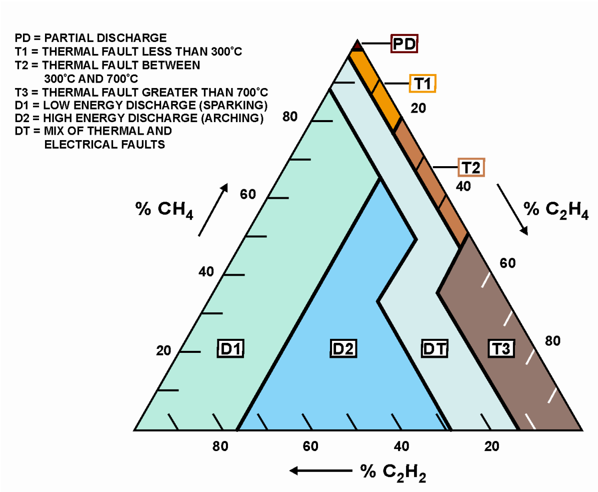

Figure 3.4: Duval Triangle

Table IV: DOERNENBURG(IEEE) Ratio:

FAULT TYPE	**R1** CH_4/H_2	**R2**C_2H_2/C_2H_4	**R3** C_2H_2/CH_4	**R4**C_2H_6/C_2H_2
Thermal decomposition	>1	< 0.75	< 0.3	>0.4
Partial discharge	< 0.1	not significant	< 0.3	>0.4
Arcing	< 0.1 to >1	>0.75	>0.3	< 0.4

Table V: Set of data used for analysis

Fault	**11kv**	**22kv**	**33kv**	**66kv**
T_1	6	4	12	9
T_2	4	6	0	4
PD	8	6	4	10
Arcing	3	1	1	2
Normal	9	13	13	5
Total	30	30	30	30

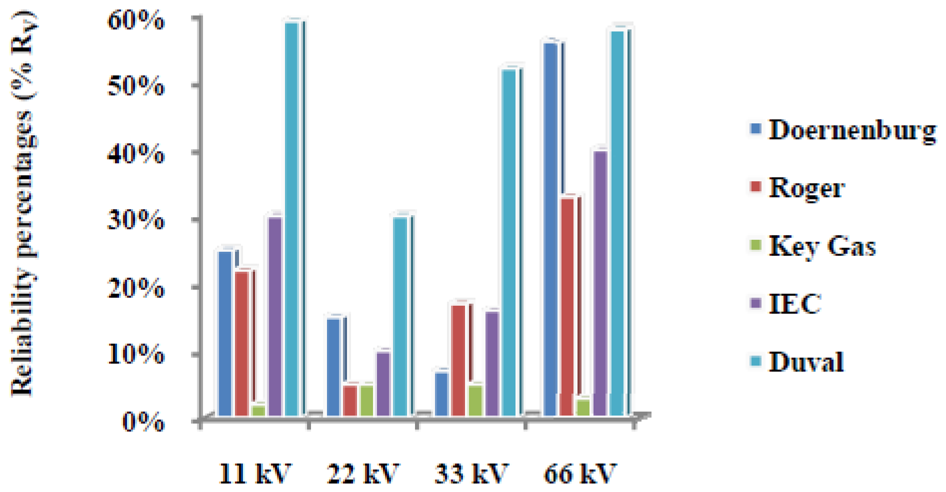

Figure 3.5: Comparison result

3.5 Analysis made using different interpretation methods

The above anlaysis is made using different interpretation techniques for different class of transformer of range below 66kv [14] as shown in table V. The conclusion between different type of faults and reliability of techniques is studied in figure 3.5 .

Chapter 4

Solubility of DGA gases

4.1 Solubility

Solubility concept can be explained as the ability of the two things to mix each other. The thing in higher amount is solvent and the thing in lesser amount is solute. Hence solubility can be explained as the ability of the solute to get dissolved with solvent. Nature of solute/solvent: Nature of solute/solvent can be anything from the three existing stages of matter

- Solid
- Liquid
- Gas

Solubility and factors affecting it : Hence from the concept of solubility there is a clear logic is that the solute should show some amount of intrest to combine with the solvent and many contribute to this thing. They are as follows:

- Temperature
- Pressure
- Nature of solute/ solvent (like dissolves in like)

4.2 Gas in Oil Solubility Concept

In DGA concept the gas is dissolved in the oil. Gas is in small amount hence it is solute. The gases that are soluble are H_2,CH_4 ,C_2H_6, C_2H_4, C_2H_2, CO, CO_2. Oil is in large amount hence the solvent . Oil used is napthanic oil. And solution thus formed is gas in liquid type of solution Hence for gas to change its solubility in oil depends on so many factors and explained as follows: Temperature: As temperature change it effects the solubility depending on the type of gas-oil interaction so for a change in temperature some gas solubility increases, decreases or remains constant . Solubility of hydrogen, nitrogen, carbon monoxide go proportionally with temperature. Solubility of carbon dioxide, acetylene, ethylene, and ethane are reversed and vary inversely with temperature changes. As temperature rises, solubility of these gases go down and as temperature falls, their solubility increase. Methane solubility remains almost constant with temperature changes. Oxygen solubility will decrease as the temperature goes up.

4.3 Role of Water in degradation of Life of Transformer

Water content in transformer (basic notes): Insulation used in transformer is of two types Solid insulation mainly consists of:

- Press board paper
- Kraft paper
- Transformer board
- Cellulose

More specifically paper insulation includes

- Paper tape
- Paper cylinders
- Transformer board cylinders
- Angle rings
- Blocks

The press boards were earlier used now the transformer board replaced it. Transformer board is made of high graded sulfate cellulose and consists of solely pure cellulose fibers. It can be completely dried,degassed and oi-impregnated

Depending on the requirement it can be manufactured of different density, shape with other properties. Presence of water in paper:

Water in paper is found in as absorbed to surface,water vapour, free water in capillaries(slots/ spaces/ cells) and imbibed free water.

Liquid insulation:

Liquid insulation used is oil. Transformer oil are of napthanic, paraffin and ester based Napthanic oils are mainly used due there operation in low temperature conditions , mainly mixture of the hydrocarbons of alkanes,napthenes and aromatic hydrocarbons

These are non polar in nature ie the show low affinity to polar compounds such as water. Water in oil is mainly in the form of dissolved state, exists in oil tightly bounded to oil molecules moisture and rarely in droplet form.

A 150MVA, 400 KV transformers typically has 80000 liters of oil and pulp/paper about 7 tons then the amount of water can in kilogram if estimated -paper contains around 223 kg of water and oil contains 2 kg of water.

Chapter 5

Case Studies

5.1 Case study 1

A 400kv step down transformer is used for the case study, the values available are in the format of relavtive ratios hence these are interpreted using the Rogers ratio [10] and ratios are given in table I.

5.1.1 DGA data interpretation:

5.1.2 Key gas method Interpretation:

- H_2, CH_4, C_2H_6, C_2H_4, and C_2H_2 are present perhaps in large amounts.
- If C_2H_2 is being generated, arcing is continuing. CO will be present if paper is being heated.
- Type of fault:The possible fault for these rise of gases is High energy discharges (arcing).
- Possible area of cause of production of gases is in tap changer or lead connections).

Table I: Rogers Ratio of 400 kV Transformer:

DAY	**C1** C_2H_2/C_2H_4	**C2** C_2H_4/C_2H_6	**C3** CH_4/H_2
1	0.37	3.4	0.66
2	0.371	3.45	0.66
3	0.382	3.4	0.44
4	0.642	3.5	0.47
5	0.621	3.7	0.36
6	0.621	3.7	0.40
7	0.68	3.6	0.40
8	0.667	3.82	0.41
9	0.65	4	0.38
10	0.74	3.45	0.40
11	0.71	3.85	0.39

- Weakened insulation from aging and electrical stress,Carbonized oil,Paper destruction if it is in the arc path or overheated.

5.1.3 Rogers interpretation:

From the roger interpretation table the code generated form the table 5.4 is

Rogers code : (1 0 2)

Fault type : High energy discharge

Problems found : Discharges (arcing) with power follow through arcing breakdown of oil between windings or coils, between coils and ground, or load tap changer arcing across the contacts during switching with the oil leaking into the main tank.

5.2 Case study 2

A autotransformers shown clear generation of faulty gases DGA data of 300MVA,500KV is taken for the study [10] and shown in the table II.

Table II: DGA data of 500 kV,300 MVA Transformer

DATE	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO	CO_2
27.09.97	1	1	4	1	1	4	49
17.10.97	53	2	1	1	2	46	235
12.11.97	154	6	2	3	2	105	684
14.05.98	447	32	11	23	1	580	1920
30.06.98	563	151	50	148	1	605	1757
23.07.98	557	155	45	156	1	588	1720
02.09.98	674	204	70	217	1	722	2174

5.2.1 Variation of Gas Concentrations:

Variation of each gas generation is plotted , to analyze the behavior of rise of each gas generation at normal condition after fault generation and to understand whether a minor fault originated is cause for major fault and there by decreasing the life time of the transformer.

5.2.2 Rogers interpretation:

The Rogers ratios for DGA data of 500kv transformer is calculated and shown in the Table III. **Day 1:**

- **Rogers code:**(1 1 0)
- **Faulty type:** High energy partial discharge
- **Problems found:** Electric discharges in bubbles, caused by insulation voids or super gas saturation in oil or cavitations (from pumps) or high moisture in oil (water vapor bubbles) and leading to tracking or perforation of solid cellulose insulation by sparking, or arcing; this generally produces $CO$and CO_2.

Day 2:

- **Rogers code:** (1 1 1)

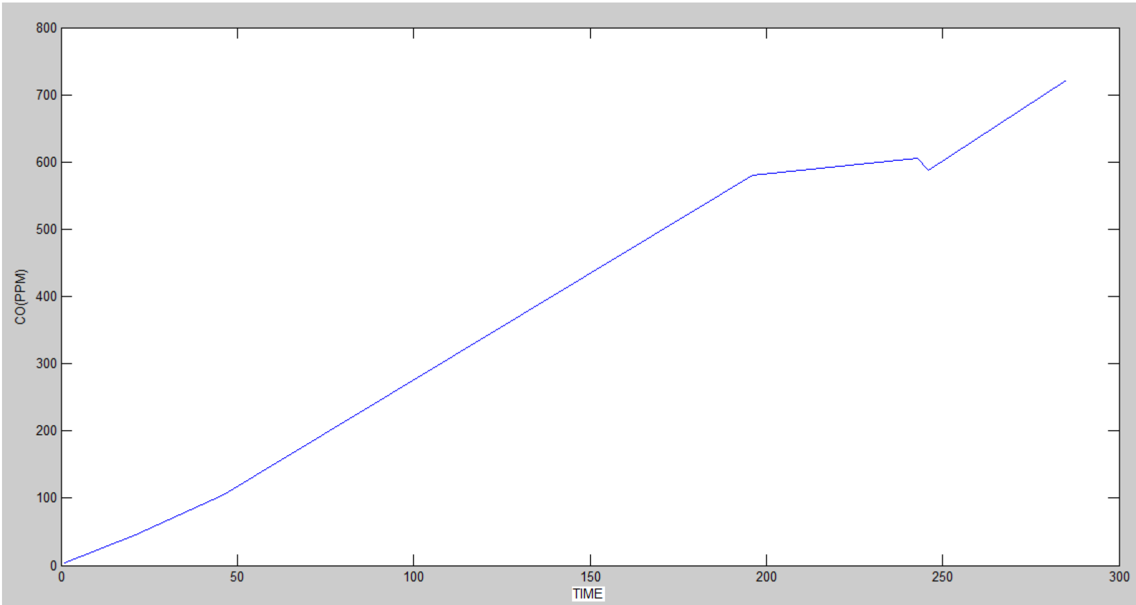

Figure 5.1: Variation of CO with time(days)

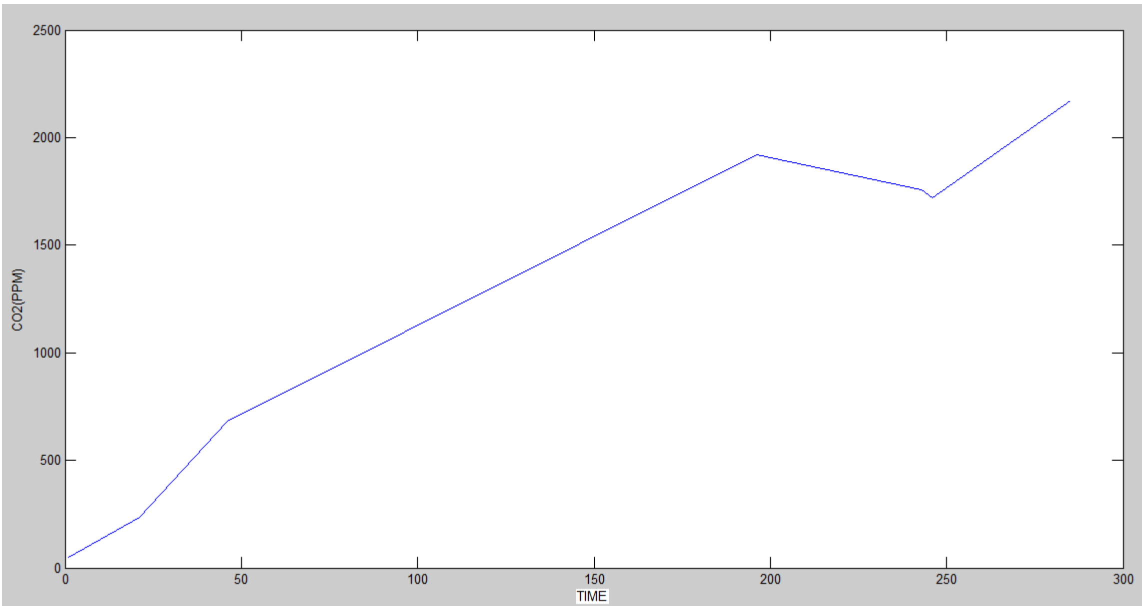

Figure 5.2: Variation of CO_2 with time(days)

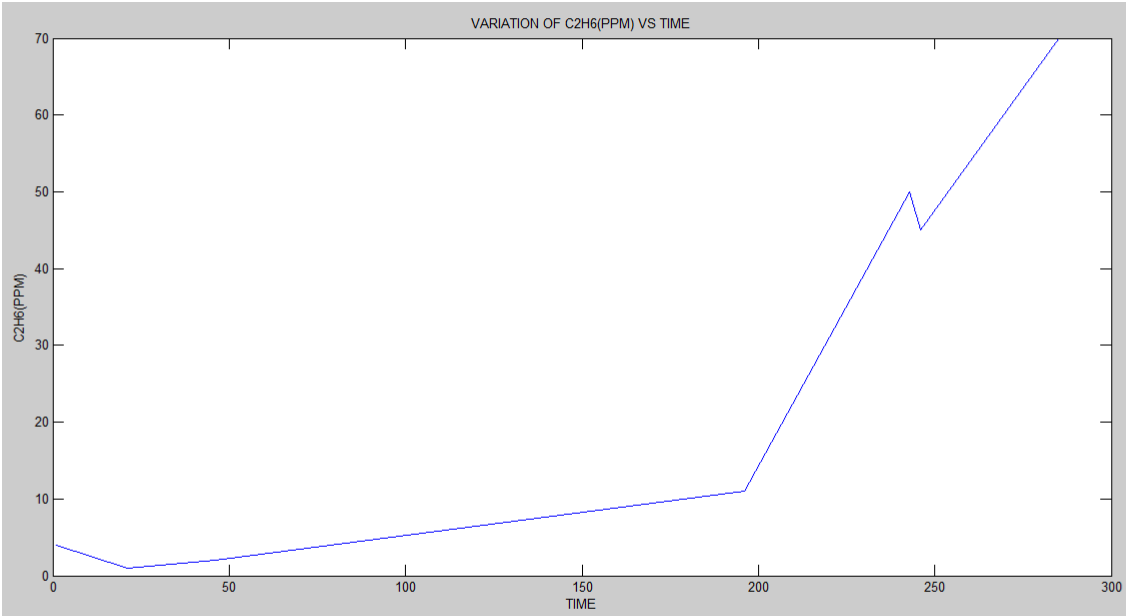

Figure 5.3: Variation of C_2H_6 with time(days)

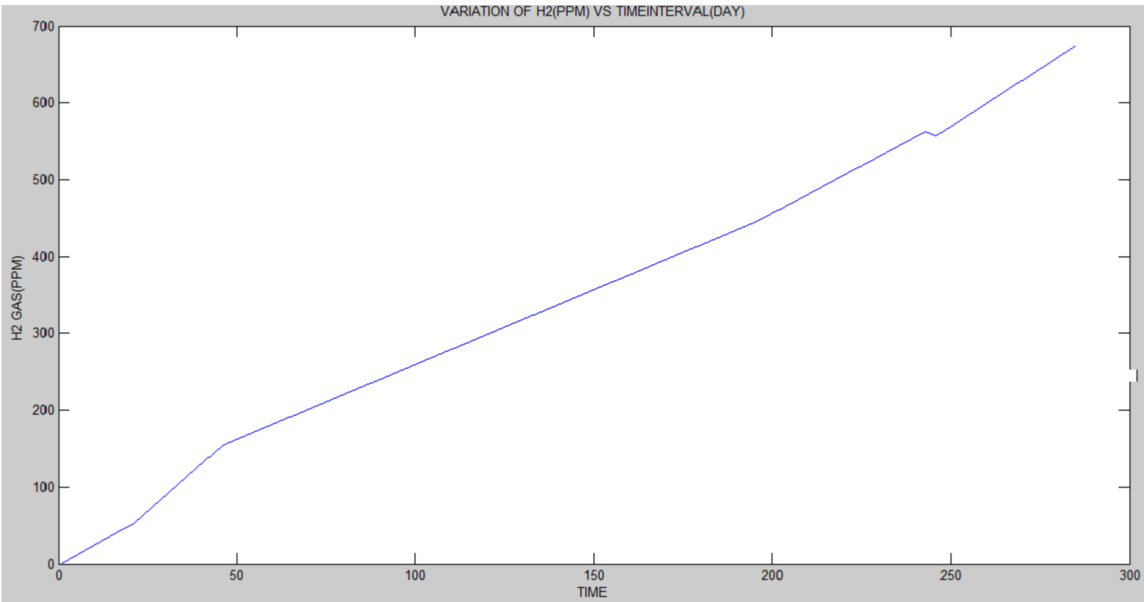

Figure 5.4: Variation of H_2 with time(days)

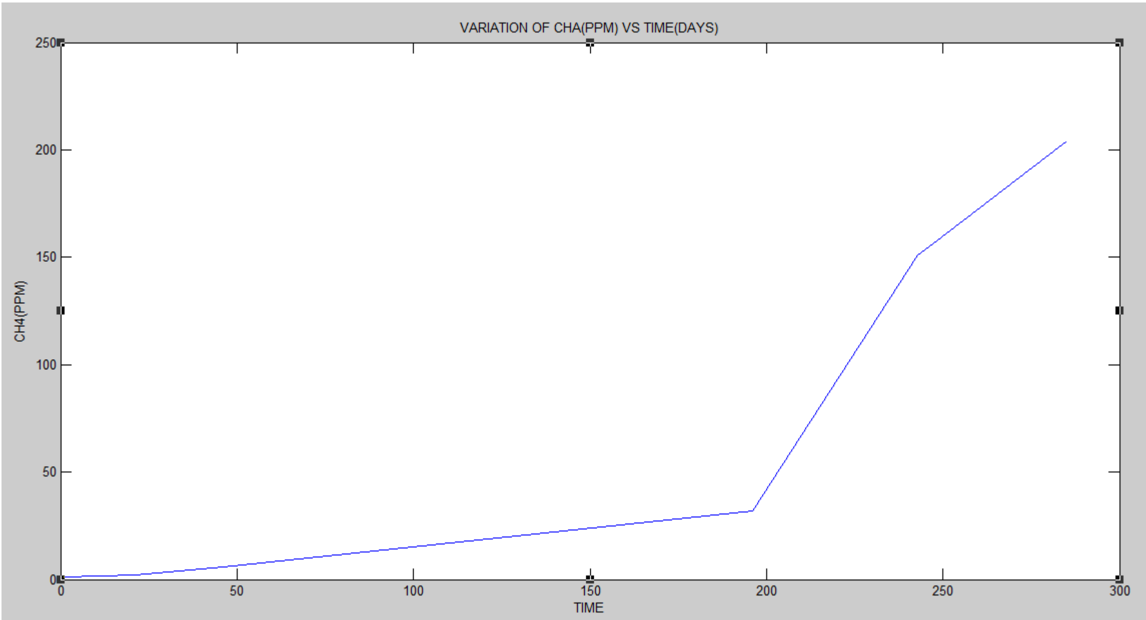

Figure 5.5: Variation of CH_4 with time(days)

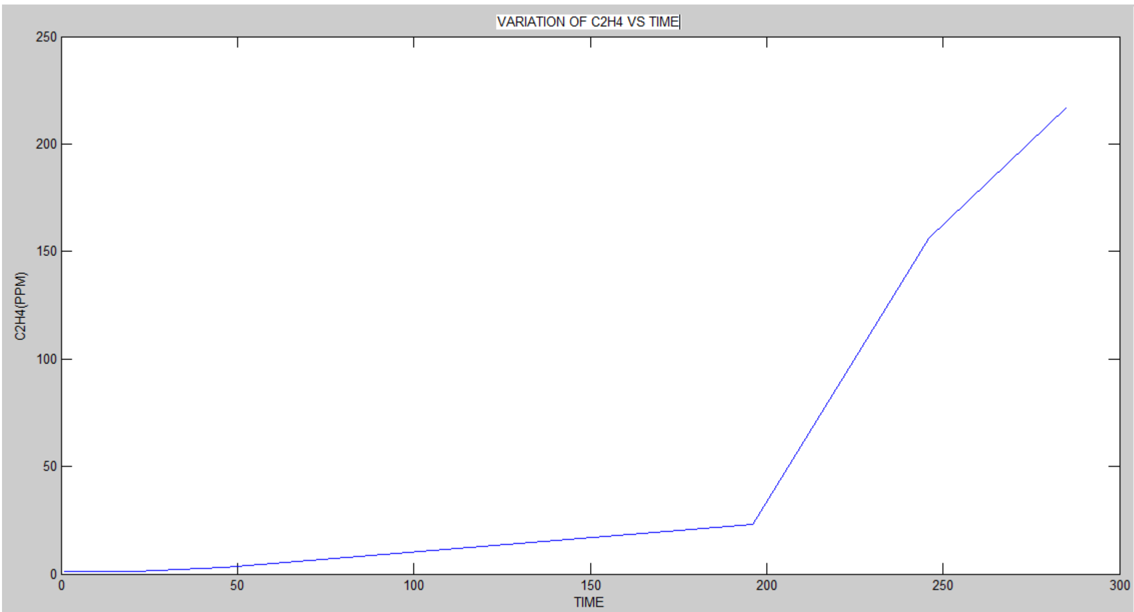

Figure 5.6: Variation of C_2H_4 with time(days)

Table III: Rogers Ratio of 500 kV Transformer:

DATE	**C1** C_2H_2/C_2H_4	**C2** C_2H_4/C_2H_6	**C3** CH_4/H_2
12.11.97	0.66	1	0.03
14.05.98	.5	2.1	0.07
30.06.98	.02	2.96	.26
23.07.98	less than 0.1	3.2	.28
02.09.98	less than 0.1	3.1	.66

- **Faulty type:** Thermal fault less than 150°C has started to occur
- **Problems found:** Insulated conductor overheating; this generally produces $CO$and CO_2because this type of fault generally involves cellulose insulation.

Day 3:

- **Rogers code:**(0 0 1)
- **Faulty type:** Thermal fault less than 150°C
- **Problems found:** Electric discharges in bubbles, caused by insulation voids or super gas saturation in oil or cavitations (from pumps) or high moisture in oil (water vapor bubbles) and leading to tracking or perforation of solid cellulose insulation by sparking, or arcing; this generally produces CO and CO_2.

5.2.3 Duval triangle interpretation

There has observed from the Rogers interpretation that there is a rise of the overheating thermal fault in the transformer . So it Duval interpretation can be done .The key gases required for the Duval interpretation ar shown in the table IV.

Table IV: Duval triangle Data of key gases:

DATE	CH_4	C_2H_4	C_2H_2
14.05.98	32	23	1
30.06.98	151	148	1
23.07.98	155	156	1
02.09.98	204	217	1

From 14.05.98-30.06.98: Final DGA values of the gases are given in the table1:

- CH_4 =151 ppm.
- C_2H_4 =148 ppm.
- C_2H_2 =1 ppm.
- TOTAL = 300 ppm.

Values of gases in percentage:

- CH_4 = 50.3 ppm.
- C_2H_4= 49.3 ppm.
- C_2H_2 = .33 ppm.

Hence from the Duval triangle interpretation it lies on the edge of thermal fault T_2 and T_3 regions in the figure 5.7.

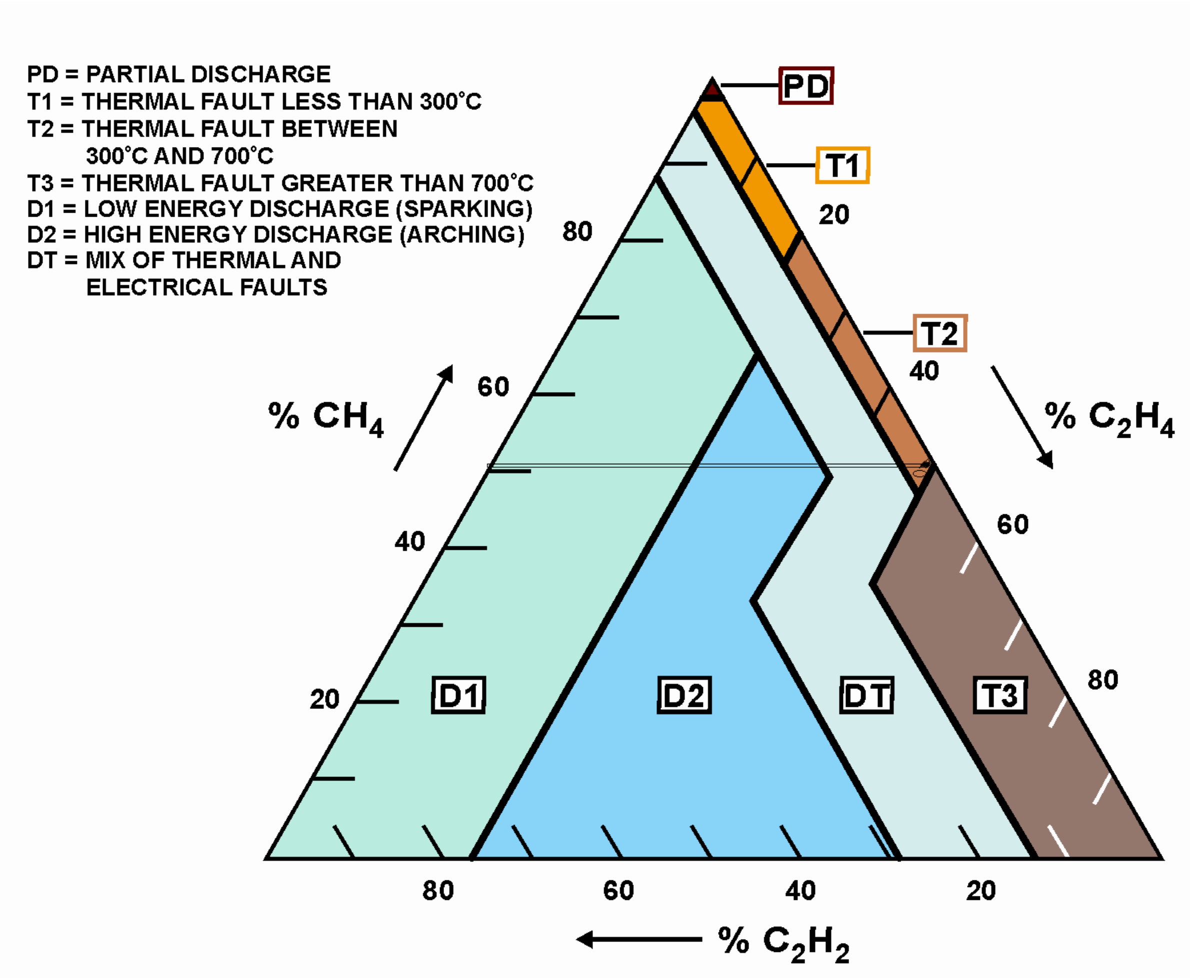

Figure 5.7: Duval triangle interpretation for key gases

There is rise in the levels of the gases

- Increase in CH_4(ppm) = 119
- Increase in C_2H_4(ppm) = 125
- Increase in C_2H_2(ppm) =0
- Total (ppm) = 244
- Increase in CH_4 =48.5 %
- Increase in C_2H_4= 51.5 %
- In this rise of gases interpretation using Duval triangle is at thermal fault T_3 in the figure 5.8 ,When the interpretation is made at the 02/09/98 the thermal fault observed is T_3 (temperature greater than700°C).

5.2.4 Conclusion:

From Duval interpretation it is clear that a fault that has occurred in the region T_2(300°C to 700°C) in two months has a thermal fault T_3 and there is increase of generation rate of gases CH_4 and C_2H_4.Rate of rise of gas level between the two consecutive faults is considered as an important factor for accurate diagnosis.

5.3 Loss of life time of transformer

In IEC standard a method to calculate the relative ageing rate is given. The model presented is only based on the insulation temperature as the controlling parameter. The relative ageing rate

$$\phi = 1,0 \tag{5.1}$$

Corresponds to a temperature of 98°C for non-thermally upgraded paper and to 110°C for thermally up-graded paper. Since the temperature distribution is not uni-

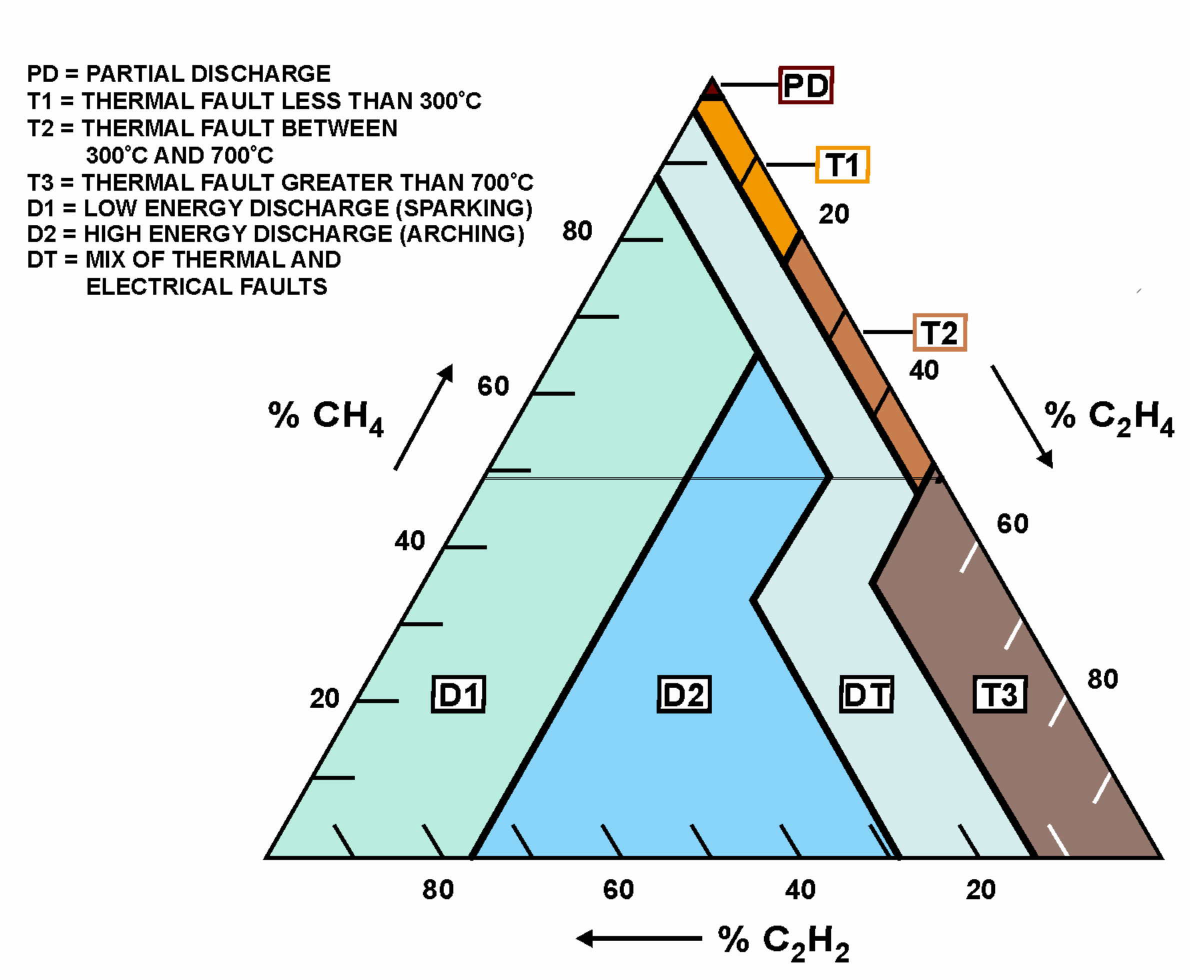

Figure 5.8: Duval triangle interpretation for gas rise rate

form, the part that is operating at the highest temperature will undergo the greatest deterioration.

Since the temperature distribution is not uniform, the part that is operating at the highest temperature will undergo the greatest deterioration. Therefore, the rate of ageing is referred to the winding hot-spot temperature.

The relative aging rate for non-thermally upgraded paper is defined according to following equation:

$$\phi = 2^{\theta-98/6} \tag{5.2}$$

where theta is the hot spot temperature.

for thermally upgraded paper :

$$\phi = e^{15000/110+273-15000/273+\theta} \tag{5.3}$$

The loss of life L over a certain period of time is defined as following:

$$L = \int_0^t \phi dt \tag{5.4}$$

Chapter 6

Rise of Gas level

The rise of gas level in the oil is given by the following equation:

G(T)= G(T-) + G(n) + G(l)+ Rate of gas rise associated with the fault.

where

- G(T)= Gas level at time T
- G(T-)=Pre gas level for time T
- G(n)= Level of Gas generation due to normal oil.
- G(l)= Gas leakage due to change in solubility of Gas in oil

6.1 Gas generation in normal oil:

The mineral oil used in the transformer depending on the composition is categorized into following ways :

1) Nytro
2) y-3(Technol)
3)TK
4)YPF-64
5) Shell diala

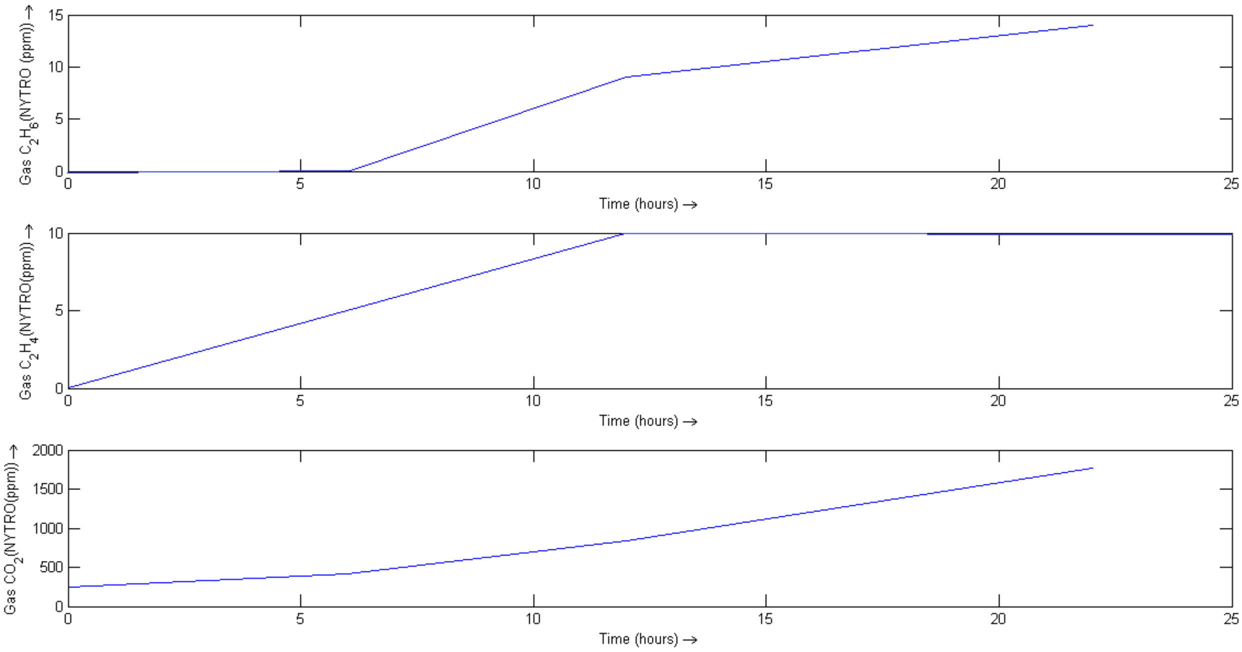

Figure 6.1: Generation of gases in nytro oil

A study by cigre has shown that some oils may produce hydrogen at temperature (below 130°C). a possible explanation may be that the catalyst used today are sufficient to produce over hydrogenated oils. It has been proposed that these contain some molecules where hydrogen atoms occupy an unstable position, a heating could release such atoms. To determined the rise of different gases and their trend of rise for a given type of oil figure 6.1, 6.2 will be helpful. From the following figures a fundamental data of different gases rise for a given oil can be taken and trend is helpful to understand how the rise will be after a period of service.

6.2 Case study:

The DGA field data of one of the 765 kv transformer in service is obtained from table I. The type of oil that has used in the transformer is Nytro type mineral oil. The

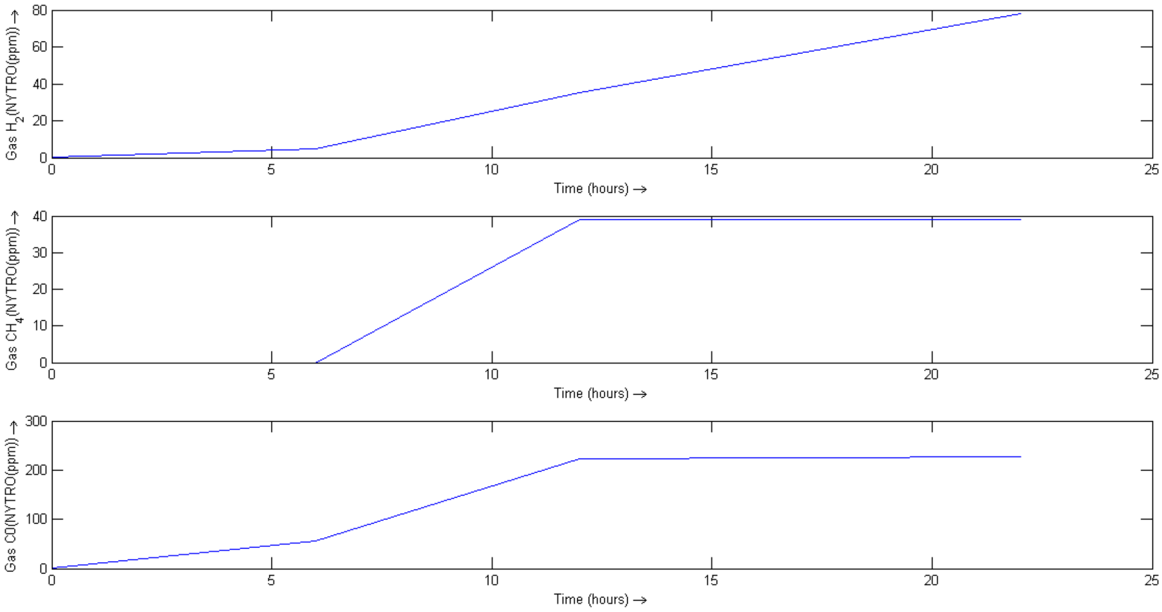

Figure 6.2: Generation of gases in nytro oil

rise of carbon di oxide and carbon mono oxide is show an increasing trend so as to understand the effects of these trends the ratio of $CO_2/CO$is calculated and plotted in figure 6.3.

6.3 DGA data interpretation enhancement:

It is important to note that the gas rise due to normal operation of the transformer is fundamentally important for any diagnostic assessment. Because the magnitude of variation is sufficient to confuse or misdirect the diagnosis process, it is important to characterize those aspects of the basic chemical composition that defines these fundamental properties. Fortunately, once they are know , the basic composition and the associated properties will generally dont change unless substantial mixing with another fluid occurs [13].

Table I: Field data of DGA of transformer using nytro oil

DATE	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO	CO_2
1.03.13	28	5	2	2	0	544	3602
31.08.13	31	7	2	2	3	715	1903
20.10.13(T)	33	6	2	2	1	755	2416
20.10.13	29	6	2	2	1	764	2428
30.01.14(T)	35	6	3	2	4	871	2321
30.01.14	31	5	2	1	3	884	2015

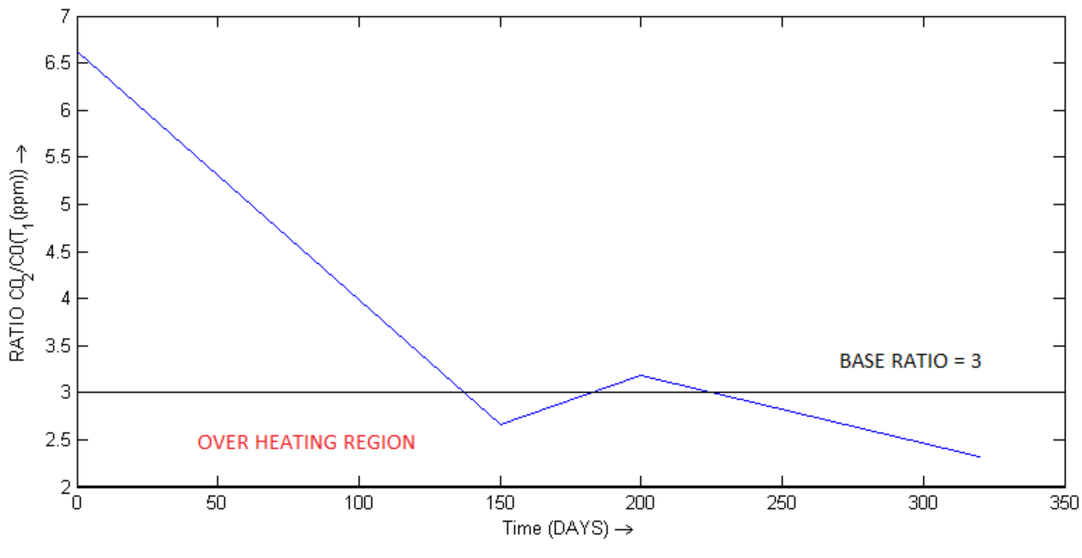

Figure 6.3: Single gas ratio Interpretation

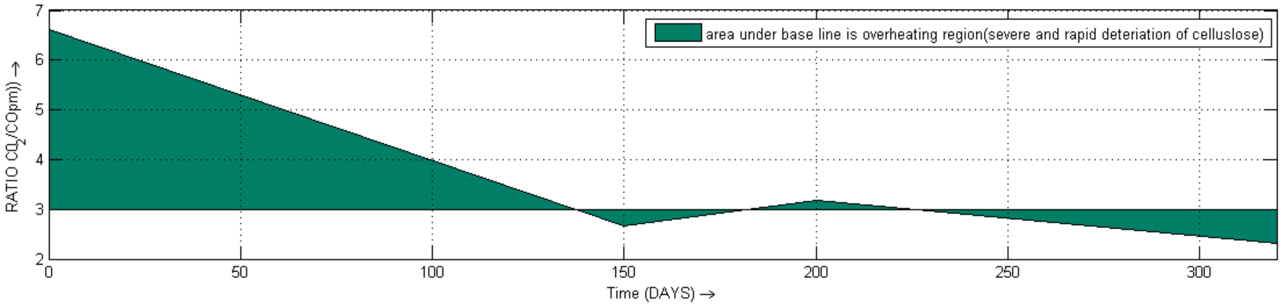

Figure 6.4: Normal single gas interpretation

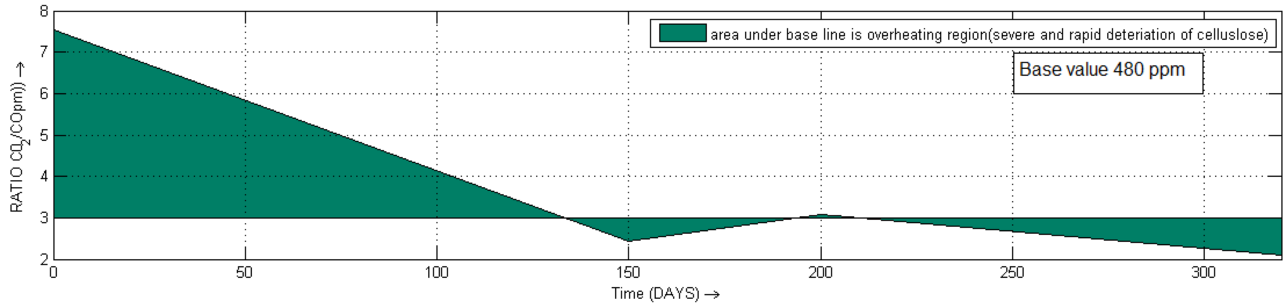

Figure 6.5: Enhanced single gas interpretation

So before interpreting the DGA data of the transformer first the data of gas rise due to normal operation has to first removed then the analysis has to be made. So as to remove the base data has to set to an fixed valued and the base gas concentration has to deducted from the gas value that is going interpreted then the interpretation made will be accurate. The enhanced single gas interpretation is shown in figures 6.4,6.5, for different base values of CO and CO_2 the enhancing of single gas ratio is observed.

Chapter 7

Gas leakage due to solubility

7.1 Factors effecting solubility:

The solubility of gas in oil is dependent on nature of oil, temperature and pressure. To calculate the amount of change in the solubility of the gas in oil it is important to know the solubility product at the reference temperature and saturation solubility of each gas in oil. The ostwalds coffecient of solubility for different gases is Table I.

The solubility trend followed by each gas in oil is as follows:

1)Solubility of hydrogen, nitrogen, carbon monoxide go proportionally with temperature.

2) Solubility of carbon dioxide, acetylene, ethylene, and ethane are reversed and vary inversely with temperature changes. As temperature rises, solubility of these gases go down and as temperature falls, their solubility increase.

3)Methane solubility remains almost constant with temperature changes.

4)Oxygen solubility will decrease as the temperature goes up.

Table lists the saturation solubility's for dissolved gases in transformer oil (% by volume). The saturation solubility for a gas is the maximum amount of gas a liquid can hold when entire of that gas is bubbled through the liquid and fills the headspace above the liquid.

Table I: Ostwalds Coefficient

SR.NO	**GAS**	**OSTWALD COEFFICIENT**
1	H_2	0.0558
2	O_2	0.179
3	CO	0.133
4	CO_2	1.17
5	CH_4	0.438
6	C_2H_6	2.59
7	C_2H_4	1.76
8	C_2H_2	1.22

Table II: Maximum Solubility of Each gas in oil

SR.NO	**GAS**	**Maximum Equivalent(PPM by volume)**
1	H_2	70,000
2	O_2	160000
3	CO	90,000
4	CO_2	1200000
5	CH_4	300000
6	C_2H_6	2800000
7	C_2H_4	2800000
8	C_2H_2	4000000

The maximum amount of oil that is soluble in oil is obtained at standard temperature and pressure where the solubility is saturated this standard temperature (0°C) and 14.7psi/29.93 inches of mercury, which is standard barometic pressure at sea level. the values of gases that are soluble in saturated oil is given in following Table II.

Table III: Ostwalds Coefficient at 0°C for mineral oil of density 0.85 kg/l

SR.NO	GAS	OSTWALD COEFFICIENT
1	H_2	0.04
3	CO	0.12
4	CO_2	1.45
5	CH_4	0.41
6	C_2H_6	2

7.2 Solubility vs temperature:

For calculation of solubility first variation of ostwalds coefficient with temperature and for different density oils is to be determined.The method uses Ostwald coefficients Lo of various gases at 0°C for petroleum liquids with the density of d=0.85 kg/L [11]. The value of the ostwald coeffficient variation is given in Table III

7.2.1 Calculation of ostwalds coefficient for different oils:

The Ostwald coefficient,L_0, of the gas is extracted from table III and it converted to the value at the desired temperature (T) using the following equation:

$$Ł_c = 0.3 * e^{0.639*700-T/T*log3.333*Lo} \tag{7.1}$$

The value of the ostwald coefficient for different oils for $CO_2$and CO is given in figures 7.1,7.2.

7.2.2 Calculation of change solubility for Shell Diala,Nytro and other oils:

Solubility of gas depends on factors such as vapor pressure of gas,density of liquid ,temperature and ostwalds coefficient,for determining the solubility the assumption of no variation of vapor pressure with temperature is considered.Therefore solubility of

Table IV: Ostwald coefficients at different temperature for different oil for CO_2

SR NO	**Temperature**	**shell diala oil**	**Nytro oil**	**New Insulating oil**	**Old Insulating oil**
1	273	1.21	1.248	1.2615	1.432
2	288	1.04	1.0793	1.0904	1.241
3	311	0.859	0.8870	0.8960	1.020
3	339	0.701	0.7240	0.7314	0.8327
3	355	0.634	0.6541	0.6607	0.7522
3	400	0.497	0.5134	0.5186	0.5904

Table V: Ostwald coefficients at different temperature for different oil for CO

SR NO	**Temperature**	**shell diala oil**	**Nytro oil**	**New Insulating oil**	**Old Insulating oil**
1	273	0.0812	0.08384	0.08470	0.09642
2	288	0.0884	0.09126	0.0922	0.1049
3	311	0.0991	0.1023	0.1033	0.1176
3	339	0.1115	0.1151	0.1162	0.1323
3	355	0.1183	0.1221	0.1233	0.1404
3	400	0.1363	0.1406	0.1420	0.1616

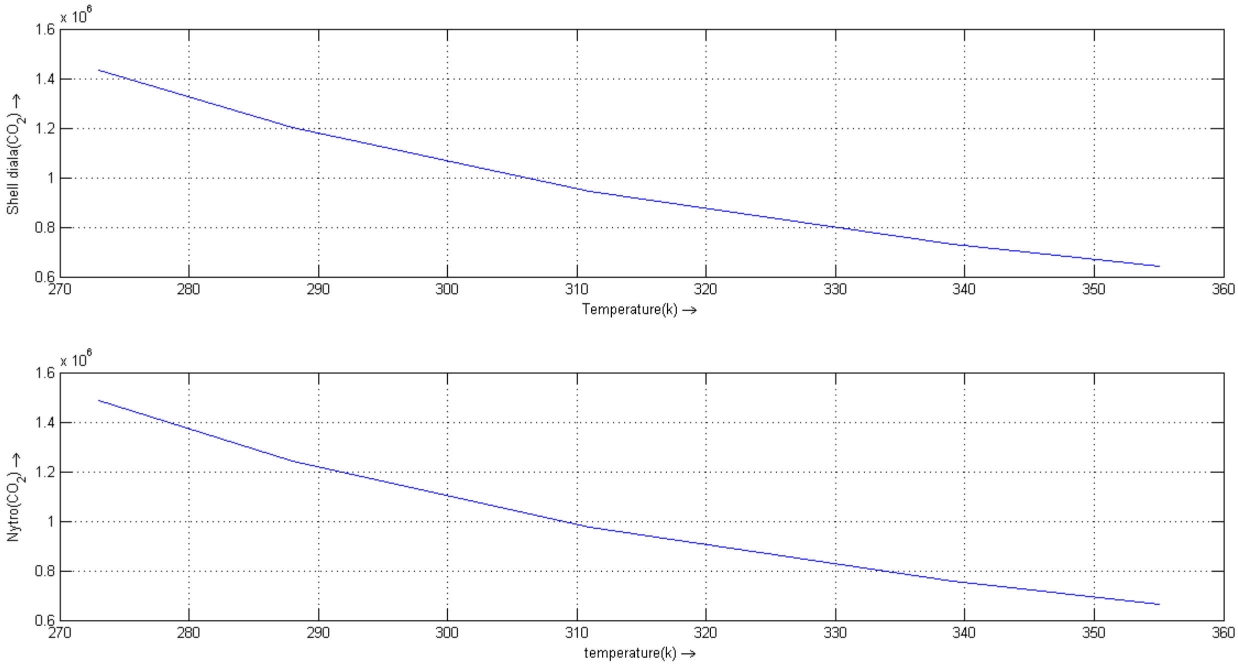

Figure 7.1: Solubilty variation for different oil of CO_2

the gas is dependent on the ostwalds coefficient , temperature and density of the oil .The solubility variation of the gas is then determined [11] and variation of solubility of CO_2 with respect to temperature for different types of oils is shown in the figures 7.1,7.2,7.3.

$$G = KL_C d[1 - 0.000595((T - 288.6)/d^{1.21})] \tag{7.2}$$

- K= constant that depends on molar mass and pressure.
- d= density of the oil.
- L_C = ostwalds coefficient at temprature T and density d.
- G=solubility of the gas in oil.
- T=Temperature of oil in kelvin.

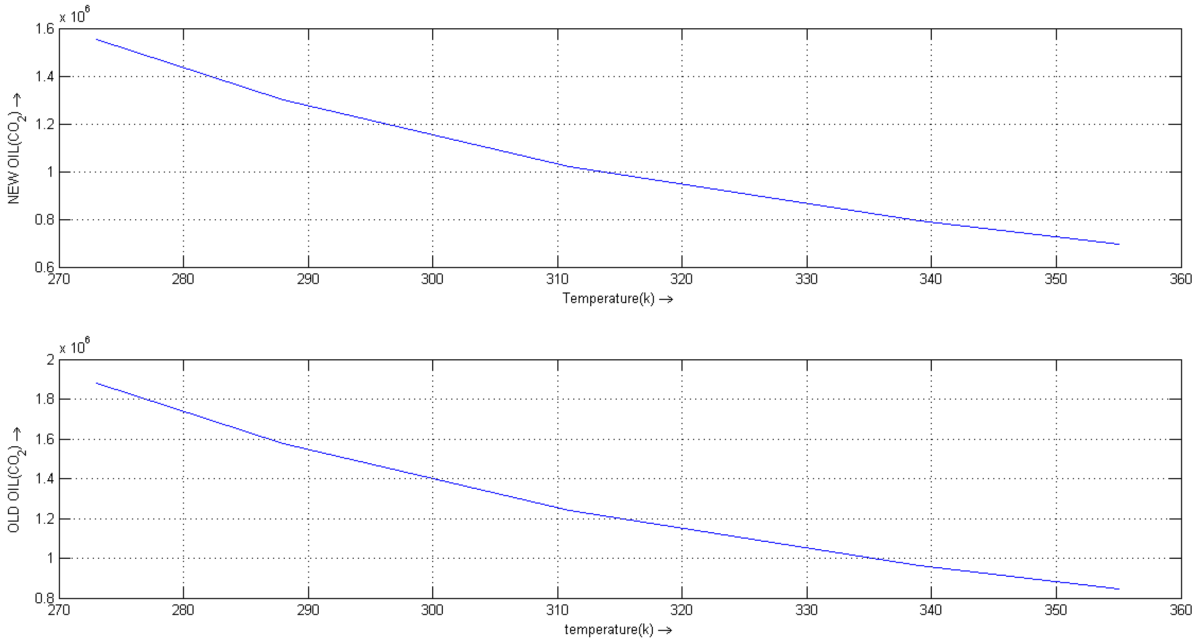

Figure 7.2: Solubility variation for different oil of CO_2

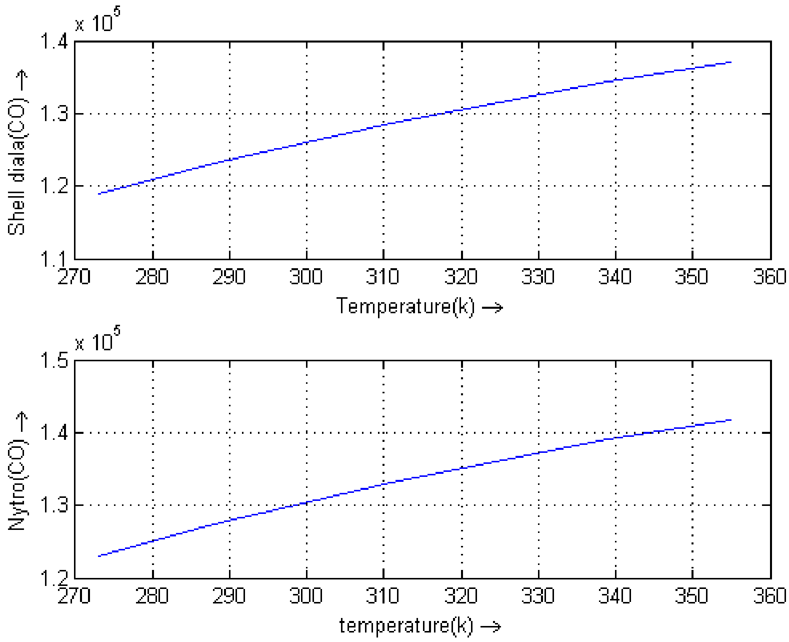

Figure 7.3: Solubility variation for different oil of CO

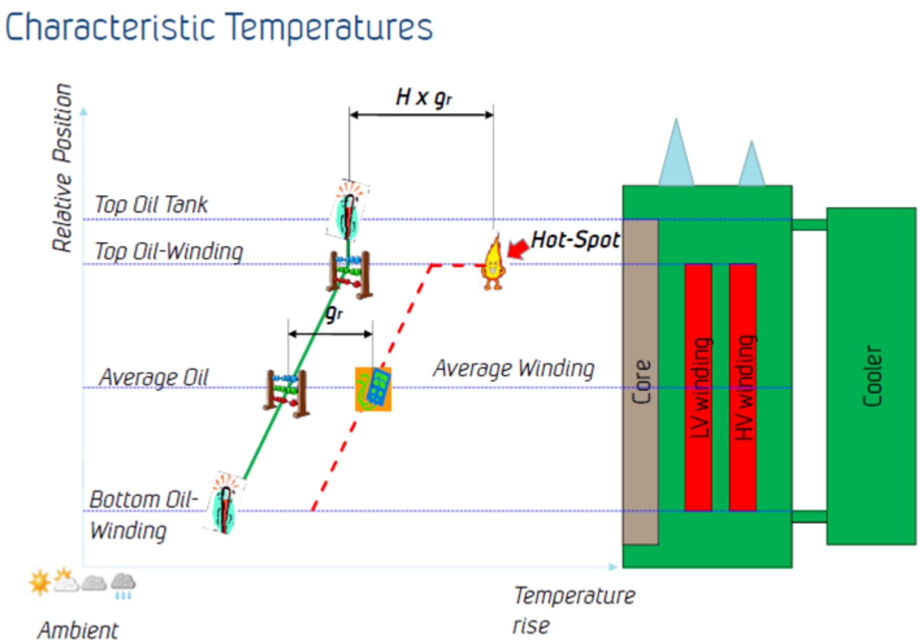

Figure 7.4: Characteristics temperature in transformer

Determination of change in solubility of CO_2 and CO: To determine the percentage change in the solubility of CO_2 and COit is required to know the temperature variation inside the transformer and the location of the gas sensor or from where the samples of the oil is taken from the transformer for DGA analysis. So a thermal diagram of 2500kva transformer with ambient temperature 24.8°C is taken from[12]and study is based on the different temperature at diffenent areas in the transformer is used for determination of solubility.

In the figure 7.5:

Point A(Top oil level):

- Oil outlet ie at the top of the oil the oil is going in to the cooler area
- At this point since the temperature is 350K the solubility of CO_2 will be less and CO will be more.

Point B(Bottom of the oil) :

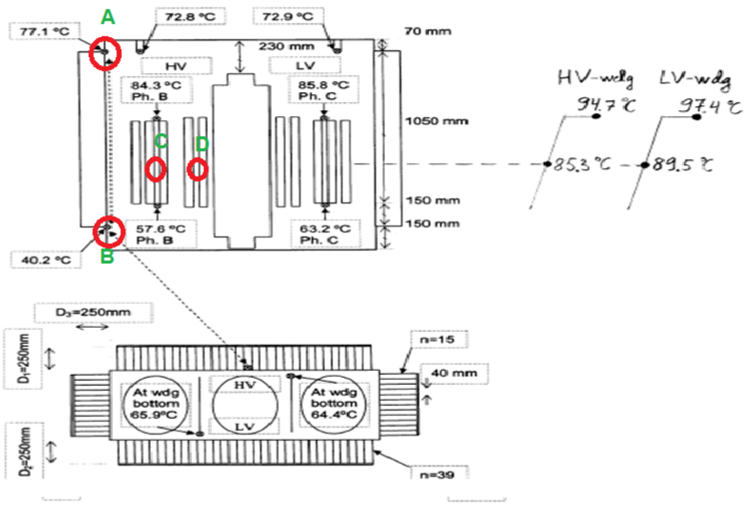

Figure 7.5: Variation of temperature at different areas of transformer

- Oil inlet to the transformer from the cooler.
- The bottom oil temperature 313K where the solubility of the gas is again changed . CO_2 is more soluble and CO is less soluble.

7.2.3 Enhanced single gas ratio method:

The proportionate change in the solubility's of the CO_2 and CO by taking figure 7.5 as reference and compared with the actual single gas ratio that has been proposed by IEC. Table IV, Table V the top and bottom oil samples are considered and when the comparsion is made the following are the outcomes:

- Single gas ratio is first calculated as suggested by IEC
- Then considering the solubility change the ratio is calculated again .
- It was found that in one case IEC single gas ratio interpretation suggests that there is no over heating and ratio value is >3 ,but when the enhance method is considered the overheating case was observed .

Table VI: Enhancement of Single gas DGA Interpretation by considering the solubility change in top oil Data

SR NO	**Top oil Data** CO_2	**top oil data** CO	**Normal Single Gas Ratio**	**Top oil Data considering solubility effect** CO_2	**top oil data considering solubility effect** CO	**Enhanced Single Ratio**
1	2416	755	3.2	2196	770	2.85
2	1903	715	2.66	1730	729	2.37
3	3602	544	6.6	3274	555	5.90

Table VII: Enhancement of Single gas DGA Interpretation by considering the solubility change in Bottom oil Data

SR NO	**Bottom oil Data** CO_2	**Bottom oil data** CO	**Normal Single Gas Ratio**	**considering solubility effect** CO_2	**considering solubility effect** CO	**Enhanced Single Ratio**
1	2428	764	3.2	2089	795	2.63
2	1903	715	2.66	1637	744	2.2
3	3602	544	6.6	3099	566	5.47

- Same method has been applied to data of 500kv transformer the results are shown in Table VI and table VII the enhancement in the single gas ratio is observed .

Table VIII: Enhancement of Single gas DGA Interpretation by considering the solubility change in top oil Data of 500kv transformer

SR NO	**Top oil Data** CO_2	**top oil data** CO	**Normal Single Gas Ratio**	**Top oil Data considering solubility effect** CO_2	**top oil data considering solubility effect** CO	**Enhanced Single Ratio**
1	1920	580	3.3	1745	591	2.95
2	1757	605	2.9	1597	617	2.59
3	2174	722	3.0	1976	736	2.68

Chapter 8

Conclusion and Future Scope

8.1 Conclusion

- The factors effecting the accuracy of the DGA interpretation is studied.
- The stray gassing (or) degassing phenomena of the oil at normal temperature is studied and applied to one of the practical cases and it found that the accuracy of the single gas ratio is enhanced.
- The influencing factors of solubility of gas in oil is studied and a variation of solubility of CO_2 and CO is mathematically deduced.
- The outcomes of the solubility variation with temperature is applied to the single gas ratio of the DGA interpretation and it is found that there is an enhancement in the DGA interpretation .
- The process of rise of gas due to different faults is explained in the figure 8.1.

8.2 Future Scope

Future scope of work includes determination of solubility change in CH_4,$C_2H_4$and C_2H_6,there by enhancing the DGA interpretation techniques Rogers and Duval.

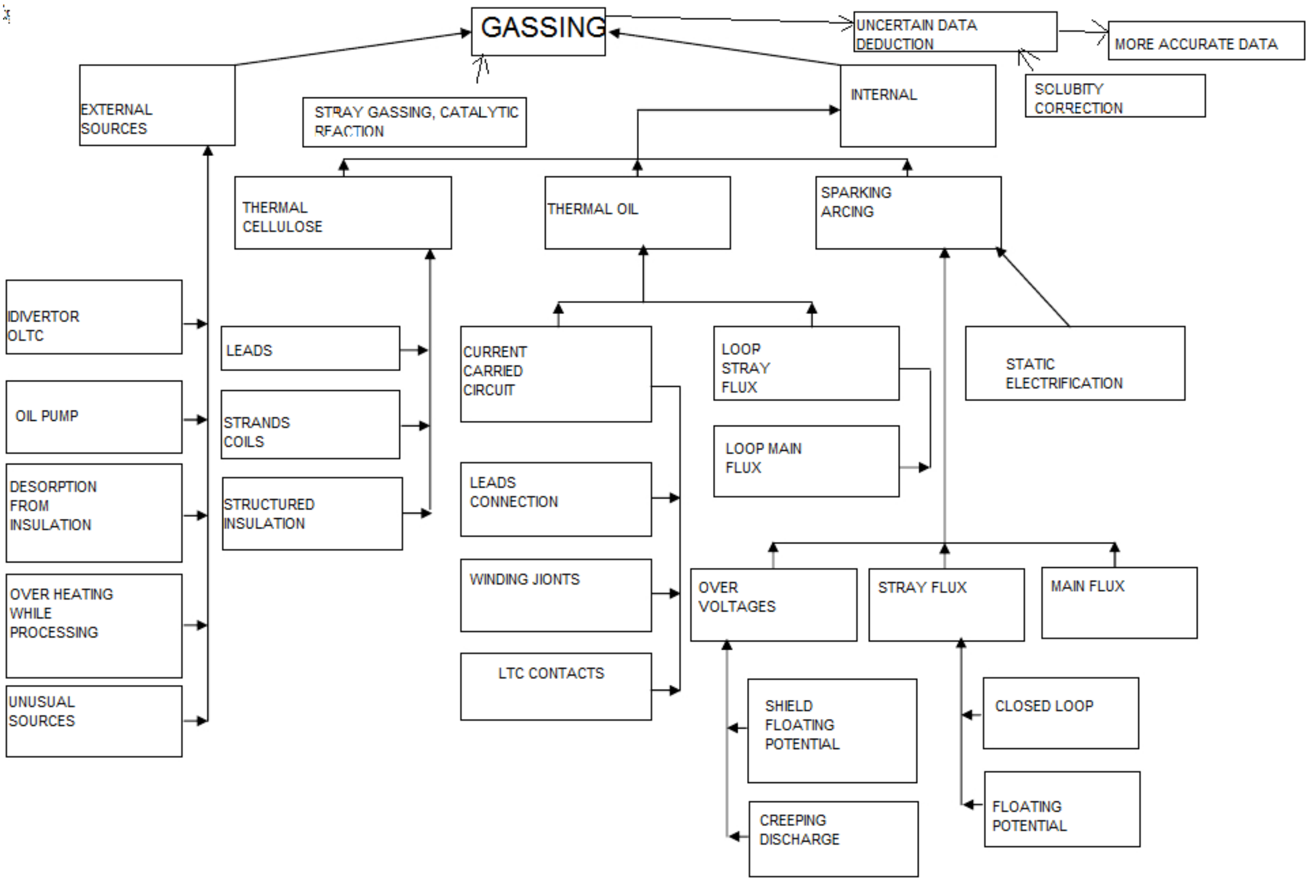

Figure 8.1: Cause of Gassing

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