DGA Interpretation for Increasing the Percent of Accuracy by Bayesian Network Method Comparing IEC TC 10 Database

Shalaka Bhimrao Wanjare[#1], P. S. Swami [#2], Dr.A.G.Thosar[#3]
[#1] *M.E. Electrical Power System, Government College of Engineering, Aurangabad, India.*
[#2] *Assistant Professor, Electrical Department, Government College of Engineering, Aurangabad, India.*
[#3] *Professor, Electrical Department, College of Engineering, Pune, India.*

Abstract

Dissolved gas analysis (DGA) is a method of estimating the presence of dissolved gases in oil of transformer. The health of transformer majorly depends on the state of transformer oil. The percentage of gases dissolve in oil may lead to different faults on transformer. Various methods are used to analyse the faults in transformer like Rogers Ratio Method (RRM), Doernenburgs Ratio Method (DRM), Duval Triangle Method (DTM), Duval Pentagon Method (DPM), and IEC Ratio Method (IRM). Various gases are evolved in transformer. The amount of dissolve gases liberated in transformer oil produces different faults. In transformer oil, usually the gases which are evolved are hydrogen (H), methane (CH_4), ethylene (C_2H_6), acetylene (C_2H_2), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen (N_2) and oxygen (O_2). This paper proposes DGA interpretation for increasing the per cent of accuracy by Bayesian network.

Keywords — *Dissolved Gas Analysis (DGA), transformer fault prediction, graphical user interface (GUI).*

I. INTRODUCTION

The main part of power system is power transformer. There are various aspects in power transformer taken into account to maintain the health of power transformer [1]. There are various fault occur in transformer which depends on various factors. One of the main reasons of it is gases formation in the transformer oil [3]. Various factors are responsible for the gaseous breakdown in transformer oil. The transformer oil is inspected and supervises to detect and maintain the proper condition of power transformer. The manufacturing cost of power transformer is very high so the reinvestment in it so is not possible therefore to maintain the good health or proper condition is important.

The reasons for occurring of faults in transformers are of two types' external fault and internal fault.

- External faults are occurring due to following reasons; External short circuit in power transformer, high voltage disturbance power transformer, power frequency over voltage.
- Internal faults in power transformer as follow; insulation breakdown among winding and earth, insulation breakdown in between different phases, insulation breakdown in between adjacent turns, transformer core fault.
- Internal earth fault in power transformer as follow: internal earth faults in a star connected winding with neutral point earthed through impedance.

The decomposition of gases occurs in oil tank of transformer responsible for the number of fault occurs in it. The gases from oil are removing by different method like

a) Partial degassing (single-cycle vacuum extraction)

b) Total degassing (multi-cycle vacuum extraction)

c) Stripping by flushing the oil with another gas

d) By the headspace technique.

Dissolved gas analysis (DGA) is technique used to recognize the fault in transformer. The normally fault is generated due to corona or partial discharge, thermal heating, arcing. For the dissimilar temperature level the different gasses are produces.

II. SUPERVISION OF OIL CONDITION

The power transformer is filled with oil. The main purpose of oil is to maintain the temperature as cool as possible and other important reason is to give insulation to the transformer windings. The oil which present in transformer tank is come in contact with the internal part of transformer. In many situation come in transformers where due to some abnormal condition the various gases are evolved within oil tank. By calculating the amount, properties of gases the fault in the transformer is categories. There are many reasons for production of gases and their breakdown. The supervision of transformer oil is takes place by various tests. The tests or maintenance work is taken place in daily, weekly, monthly according to the fault generation. The DGA took place by four steps.

a) Sampling of oil in the transformer oil tank.

b) Extraction of gases

c) Analysis of the extracted gas mixture by gas Chromatograph, gas chromatography.
d) Interpretation of the analysis.

By following above steps the oil in transformer tank is supervise and amount of gases produce in it are detected.

List of gases produce in transformer oil tank-

- Hydrogen-H_2
- Methane-CH_4
- Ethylene-C_2H_4
- Ethane-C_2H_6
- Acetylene-C_2H_2
- Propene-C_3H_6
- Propane-C_3H_8
- Carbon monoxide-CO
- Carbon dioxide-CO_2
- Oxygen-O_2
- Nitrogen-N_2

1. TABLE
FAULTS DETECTABLE BY DGA

Sr. no.	Symbol	Fault
1	PD	Partial Discharges
2	D_1	Discharges of low energy
3	D_2	Discharge of high energy
4	T_1	Thermal fault, Temp<300^0C
5	T_2	Thermal fault,300<Temp<700^0C
6	T_3	Thermal fault, Temp>700^0C

2. TABLE
GUIDELINES AND STANDARD FOR DGA

Standard	Description
IEEE Std .C57.104.2008	IEEE Guide for the analyzing of gases evolved in transformer
IEEE Std.C57.12.80-2002	Terminology for power and distribution transformer
IEEE 60599-2007-05	Mineral oil infused electrical equipment in service
IEC 60599-2007-05	reference to Duval Triangle

III. PROPERTIES OF OIL

The oil gets polluted with water and some foreign particles. The other aspect is the continuous ageing of the oil. Apart from these protecting properties these oxidation products also cause accelerated deprivation of the cellulose insulation. The number of tests is carried out to detect the properties of oil as below.

1 Electrical properties
1.1 Breakdown voltage (IEC 60156)
The ability of the oil to resist electrical stress is very imperative. The low breakdown voltage is due to contamination of oil.
1.2 Dielectric dissipation factor (IEC 60247)
This property gives the idea about dielectric losses in the oil. It gives the indication about metal ions and acids.
2 Chemical properties
2.1 Water content (IEC 60814)
The reason of moisture evolution is aging of oil. The leakage of water also occurs in transformer tank. Due to high water presence the lower breakdown voltage occurs. The proportion of aging of insulation paper is due to high water content.
2.2 Acidity (IEC 62021)
Acids are form due to oxidation in oil. The potassium hydroxide is use to neutralize the acids.
2.3 Inhibitor content (IEC 60666)
To slow down the oxidation of oil inhibitors are added. It does not allow chain reaction in the oxidation. Due to inhibitor the oil normally age very slowly. The oxidation takes place very rapidly due to lack of inhibitor. So the monitoring of inhabitation content is very important.
3 Physical properties
3.1 color (ASTM D1500)
Color is not that much important property. But it gives the idea about the aging of oil. And also for chemical analysis it is very important.
3.2 Interfacial tension (IFT ASTM D 971-99)
The amount of polar pollutants and dilapidation products accounts to interfacial tension between oil and water. It is important to indicate aging and it is also predisposed by non-acidic oxidation products.
3.3 Corrosive sulphur (IEC 62535)
Due to copper sulphide in the cellulosic insulation many problems arrived in equipment. Other problems are arriving due to corrosive sulphur components in oil. Apart from ASTM D1275 or DIN 51353 new tests developed which have higher sensitivity for detecting mechanical failure.

IV. DGA STANDARD DIAGNOSIS METHODS

A. Duval Triangle Method (DTM)

In the Duval Triangle one technique fault diagnosis is done by two ways, the classical way is by using three gases such as CH_4, C_2H_4 and C_2H_2 they are form by difference in energy. The Duval triangle 4 methods use H_2, CH_4 and C_2H_6 gases to diagnose faults of low energy or temperature. Duval triangle 4 catalogue first with Duval triangle 1 faults like PD, T1, and T2. It never detects electrical faults like D1 or D2. Duval triangle 4 is commonly discriminate between stray gassing of oil, overheating at below 250^0c, possible carbonization of paper at above 300^0C, corona partial discharge. Duval triangle 5 uses gases CH_4, C_2H_4 and C_2H_6 for fault detection of high temperature.

B. Duval Pentagon method (DPT)

In this method five main hydrocarbons gases ratio use to identify faults. The hydrocarbon gases are H_2, CH_4, C_2H_6, C_2H_4 and C_2H_2. In this method five gas ratios in a pentagon representation the faults forming in oil filled equipment's.

C. IEC Ratio method (IRM)

IEC ratio method used advance technique to identify different faults. The faults are classified in seven types partial discharge (PD), low energy discharge (D1), high energy discharge (D2), thermal faults (T1), thermal fault (T2), thermal faults (T3). In this method state assessing uses restrictions for various gases and three dissimilar gas ratios is evaluated.

3. TABLE
GUIDELINES AND STANDARD FOR DGA

Gas	Limit (external OLTC)	Limit (Internal OLTC)
H_2	60-150	75-150
CH_4	40-110	35-130
C_2H_2	3-50	80-270
C_2H_4	60-280	110-250
C_2H_6	50-90	50-70
CO	540-900	400-850
CO_2	5100-13000	5300-12000

D. Doernenburg Ratio method (DRM)

In Doernenburg Ratio method four different gases are used to evaluate three different faults. This method has limitations for each gas which is described as below table. If the gas limit increase beyond the limitation the ratio will be change which has different value when fault is diagnose.

4. TABLE
DOERNENBURG RATIO LIMITS

Fault diagnosis	CH_4/H_2	C_2H_2/C_2H_4	C_2H_2/CH_4	C_2H_6/C_2H_2
Thermal Decomposition	>1.0	<0.75	<0.3	>0.4
Corona	<0.1	-	<0.3	>0.4
Arcing	0.1-1.0	>0.75	>0.3	<0.4

E. Key gas method

In key gas method identification of key gases is done. And fault is diagnoses which are recommended by IEEE C57.104 [3]. The quantity of gas is calculated in standings as total inflammable gases. The drawback of this technique is that the analysis by the definite gases is tough in preparation since each embryonic fault produce dashes of other gases in accumulation to the key gas of such fault.

F. Rogers Ratio method (RRM)

Rogers ration method evaluates six types of fault conditions. In this method takes ratio of three gases

5. TABLE
ROGER'S RATION LIMITS

Case	Fault diagnosis	C_2H_2/C_2H_4	CH_4/H_2	C_2H_4/C_2H_6
0	Unit Normal	<0.1	0.1-1.0	<1.0
1	Low Energy density arcing	<0.1	<0.1	<1.0
2	High Energy Discharge Arcing	0.1-3.0	0.1-1.0	>3.0
3	Low Temperature	<0.1	0.1-1.0	1.0-3.0
4	thermal faults $<700^0C$	<0.1	>1.0	1.0-3.0
5	Thermal faults $>700^0C$	<0.1	>1.0	>3.0

V. BAYESIAN NETWORK

Bayesian networks usage stochastic graphical representations to explain reliance between arbitrary variables [7]. They are represented as graphs which are known as directed acyclic graphs (DAG).The structure of BN model is interpretable as every stage will be calculated as the fault condition or any abnormality which occur in the power transformer. In the BN model nodes are formed which depends on the parent nodes. There are various rules which have to satisfy for the evaluation of the form nodes. Bayes' theory states that the subsequent probability can be predictable by multiplying the opportunity and the previous probability and standardizing with the probability of evidence. Thus the evidence based software has delivered guidelines for leading systematic procedure for operation.

The Bayesian network methods offer an accepted statistical framework to substantiation based decision making by integrating a unified summary of the existing evidence and linked hesitantly through the valuation of utilities.

In BN model variables are represented as nodes. In specific given model structure we calculate the joint probability circulation both qualitative and quantitative characteristics need to be contemplate when constructing a BN. The quantitative phase on the other side deals with approximating the limitations such as particle prior and obstructive probability tables in unconditional cases, the computational of a chance of interest is termed interference.

Following figure shows the projected evidence combination framework which is constructed by using RRM, DRM and Duval's triangle method. The method is progressed in five steps.

1. Cross-validation: in the cross-validation stage the validation and assess are simplify to an independent dataset. It start with the trail counter 0 which followed by randomly shuffled the available data and feed the data for the next stage. but it the trials are less than the maximum trials than increase the trial counter by 1. Otherwise particular mean and standard deviations of the store diagnosis result.
2. Data pre-processing: the actual gas contains values are taken which are different for different gases. And the data is reshuffled and pass for the next process.
3. Parameter learning and interference through BN: in this stage the presses data is individually by each method. Every case is examined by three methods and classification ratio is calculated by each method and final decision is made about fault generation of each method. After this BN theory is applied next stage is implementation of the parameter learning. According to IEEE standard the decision is made. The fault with the maximum probability is the final judgment of the model.
4. Evidence Combination: by above data decision is made with the maximum confidence in is accuracy, But sometimes conflicts are form due to difference in decision. With the help of BN model the conflicts are resolve by taking maximum probability answer as a final result with increase accuracy.

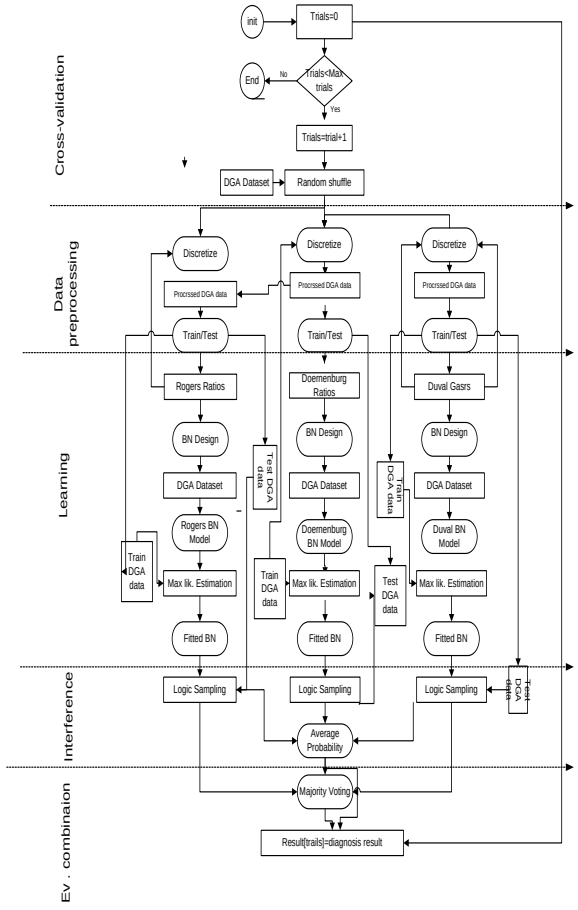

Fig 1: Bayesian network framework

6. TABLE

FAULT CODES REPRESENTATION IN GUI

Representation	Fault Type
N	Normal Operation
T1	Thermal Fault $t<300^0C$
T2	Thermal Fault $300^0C<t<700^0C$
T3	Thermal Fault $t>700^0C$
PD	Partial Discharge
D1	Arching(low intensity)
D2	Arching(high intensity)
UN	Unpredictable

Fig 2.Fault codes representing in GUI

VI. RESULT

In this paper a graphical user interference (GUI) based on MATLAB is developed to get the proper fault analysis of the transformer. In GUI point and click based application software is developed. In GUI there is no need of learning any command or program to run the application. In below figure screen shot of transformer fault analysis using GUI in MATLAB is shown.

Many data input such as specification of transformer gases (hydrogen, acetylene, ethylene, methane, ethane, carbon dioxide, carbon monoxide) are form during various abnormal condition. The data is feed and analysis of fault condition at
Different fault condition at various points of time and give the analysis of fault condition occurs in the transformer.

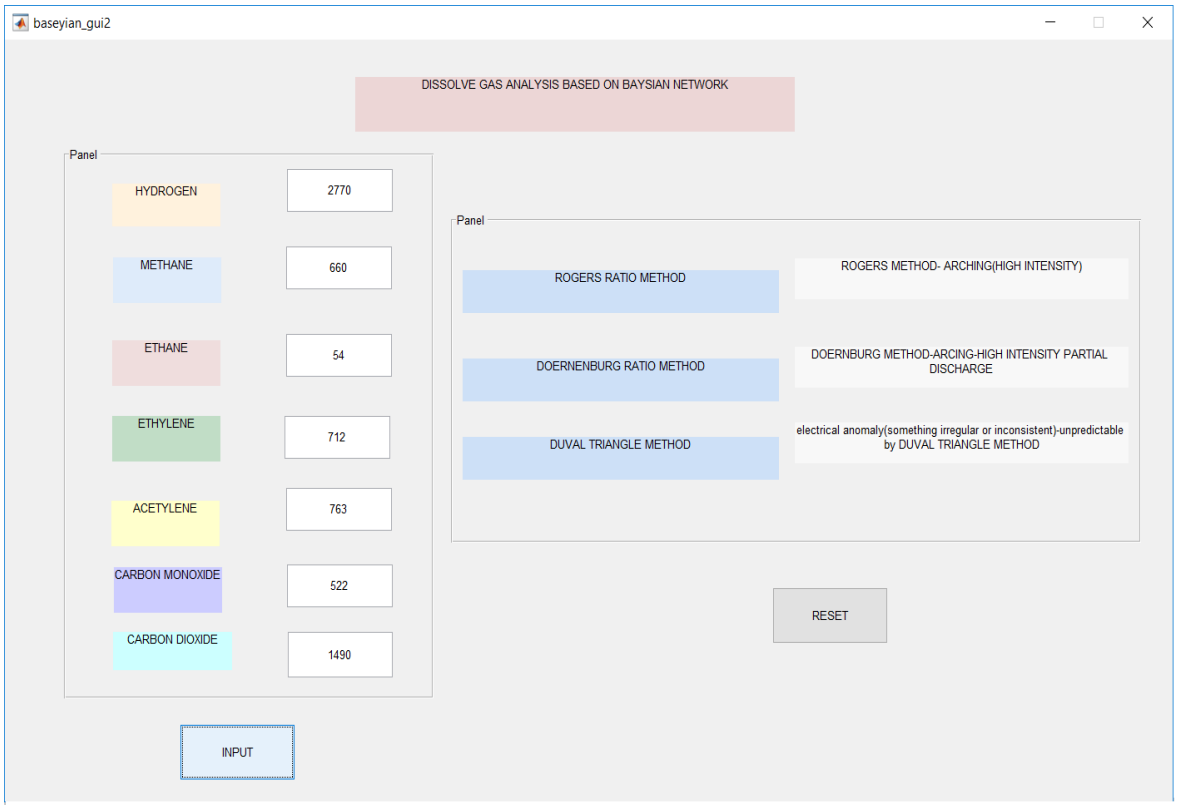

Fig 2: Output of GUI Window

7. TABLE

CALCULATION OF RESULTS BY USING DGA DATA [13]

Sr No.	Hydrogen	Methane	Ethane	Ethylene	Acetylene	Carbon Monoxide	Carbon Dioxide	RRM	DRM	DTM	IEC Result	Prediction
1	37800	1740	249	8	8	56	197	PD	PD	PD	PD	PD
2	305	100	33	161	541	440	3700	D1	D1	D1	D1	D1
3	440	89	19	304	751	299	1190	D1	D1	D1	D1	D1
4	1270	3450	520	1390	8	483	44500	T1	T3	T3	T3	T3
5	8800	64064	72128	95690	0	290	90300	T1	T3	T3	T3	T.3
6	9340	995	60	6	7	60	620	PD	UN	PD	PD	PD
7	543	120	41	411	1880	76	2800	D1	D1	D1	D1	D1
8	2850	89	19	304	757	299	1190	D1	D1	UN	D1	D1
9	360	610	1500	6990	33	573	4640	T1	T3	T3	T3	T3
10	1100	1600	221	2010	26	0	1430	T1	T3	T3	T3	T3
11	36036	4704	554	5	10	6	347	PD	UN	PD	PD	PD
12	645	86	13	110	317	74	114	D1	D1	D1	D1	D1
13	13500	6110	212	4510	4040	8690	1460	D1	UN	D1	D1	D1
14	960	4000	1290	1560	6	15800	50300	T1	T3	T3	T3	T3
15	40280	1069	1060	1	1	1	0	PD	PD	PD	PD	PD
16	6870	1028	79	900	5500	29	388	D1	D1	D1	D1	D1
17	3090	5020	323	3800	2540	270	400	T1	UN	D1	D1	D1
18	480	1075	298	1132	0	454	1000	T1	T3	T3	T3	T3
19	860	1670	30	2050	40	10	690	T1	T3	T3	T3	T3
20	26788	18342	2111	27	0	704	0	N	UN	PD	PD	PD
21	120	25	1	8	40	500	1600	D1	N	D1	D1	D1
22	535	160	16	305	680	172	338	D1	D1	UN	D1	D1
23	4000	400	70	600	6	800	218	UN	PD	T3	T3	T3
24	1550	2740	816	5650	184	1140	9360	T1	T3	T3	T3	T3
25	1000	500	500	400	1	200	1000	N	D1	PD	D1	PD

8. TABLE
COMPARISON OF DGA METHODS

Methods	Right prediction (cases25)	wrong prediction (cases25)	unpredictable decision (cases 25)
Roger's Ratio Method	13	11	1
Duval's Triangle Method	18	5	2
Doernebu rg's Ratio Method	22	1	2

VII. CONCLUSION

In this paper numerous fault in the transformer are analysis, which gives the idea about the health condition of power transformer. The work in the graphical user interface (GUI) in MATLAB is mainly focus on the calculating the exact occurring fault at the point of time. MATLAB graphical user interface (GUI) based program relate the results obtained mathematically and using the program and analysis the result as per the standard.

DGA is a method that concentrates on the amount of dissolved gases at that period of time. Classical methods like RRM, DRM, and DTM are used here for the design making of fault produce at the different concentration of gases. This method is proposed so as to improve the precent of accuracy. So that the diagnostic result of proposed model is a deterministic probability value and relate it with the obtain data. This may overcome the conflicts about the decision of the fault by individual methods, due to this Bayesian method the decision is made by maximum probability.

The result obtained in this paper can be used as comparison by IEC TC 10 dataset [13].according to this the fault can be classified as partial discharge (PD), normal operation (N), thermal fault (T1, T2, T3), arching (D1, D2) etc. according to this BN model method the accuracy can be achieved up to 88.9%.

REFERENCES

[1] Shalaka Bhimrao Wanjare, "DGA interpretation for increasing the percent of accuracy by different methods: A Review,28 March 2018.

[2] Barin G. Steward, Jose Ignacio Aizpurua, Stephen D. J. McArthur, and Victoria M. Catterson, " Improving the Accuracy of Transformer DGA Diagnosis in the Presence of Conflicting Evidence," Electrical insulation conference (EIC), Baltimore, MD,USA.

[3] M. Duval, "A review of faults detectable by gas-in-oil analysis in transformers," IEEE Electr. Insul. Mag., vol. 18, pp. 8-17, 2002.

[4] R. R. Rogers, "IEEE and IEC Codes to interpret incipient faults in transformers, using gas in oil analysis," IEEE Trans. Dielectr. Electric Insul. Vol. EI-13, pp. 349-354, 1978.

[5] "IEEE Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers," IEEE Std C57.104-2008, pp. 1-36, 2009.

[6] K. Spurgeon, W. H. Tang, Q. H. Wu and G. Moss, "Dissolved gas analysis using evidential reasoning," IEE Proceedings - Science, Measurement and Technology, vol. 152, pp. 110-117, 2005.

[7] M. Duval "Interpretation of gas-in-oil analysis using new IEC publication 60599 and IEC TC 10 databases," IEEE Electr. Insul. Mag., vol. 17, pp. 31-41, 2001

[8] H.-C. Sun and C.-M. Huang, "A Review of Dissolved Gas Analysis in Power Transformers," Energy Procedia, vol. 14, pp. 12201225, 2012

[9] A. Abu-Siada and S. Islam, "A new approach to identify power transformer criticality and asset management decision based on dissolved gas-in-oil analysis," Dielectrics and Electrical Insulation, IEEE Transactions on, vol. 19, pp. 1007-1012, 2012.

[10] M. Duval and J. Dukarm, "Improving the reliability of transformer gasin-oil diagnosis," Electrical Insulation Magazine, IEEE, vol. 21, pp. 2127, 2005.

[11] S. Corporation, "Serveron White Paper : DGA Diagnostic Methods," 2007.

[12] M. Duval, "New techniques for dissolved gas-in-oil analysis," Electrical Insulation Magazine, IEEE, vol. 19, pp. 6-15, 2003.

[13] M. Duval and A. dePabla, "Interpretation of gas-in-oil analysis using new IEC publication 60599 and IEC TC 10 databases," IEEE Electrical Insulation Magazine,vol. 17, pp. 31-41, 2001.