International Journal of Engineering Science Invention (IJESI)
ISSN (Online): 2319-6734, ISSN (Print): 2319-6726
www.ijesi.org ||Volume 10 Issue 3 Series I || March 2021 || PP 53-68

Simulation of DGA Analysis for Power Transformer Using Advanced Control Methods

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ABSTRACT: *In any power system or grid network transformer device use for power from one circuit to another circuit without changing the frequency with high-efficiency levels. Due to the number of usages, transformer protection is very important nowadays for electric supply, which is fault-free, efficient, and increases the transformer life cycle. This paper is a brief discussion about the concentration of different gases like CO, CO2, H2, C2H6, C2H4, C2H2, and CH4 related faults, known as DGA analysis. The help of various classical techniques gives different conditions for the same sample unit. This paper presents MATLAB simulation of ANN and Machine learning-based high accuracy design techniques for DGA analysis. The results are compared with the classical methods like Key Gas Method, IEC Ratio method, Duval triangle Method, and Rogers Ratio Method. Still, in this paper, we have done only Duval triangle Method for Comparison using Matlab. The proposed methods' simulation result shows that overall DGA analysis using a Machine learning algorithm is better than conventional Duval triangle method Performance.*

KEYWORDS: *DGA, Duval Triangle, IEC Ratio, Rogers Ratio, etc.*

Date of Submission: 20-03-2021 Date of Acceptance: 04-04-2021

I. INTRODUCTION

The DGA is very important for transformer fault analysis for many years. In a transformer, we know that transformer oil is necessary for insulating material and cooling purposes. Due to temperature and discharge in oil, different gases like C2H6, C2H4, C2H2, and CH4 are dissolved in oil which makes failure or breakdown of transformer oil. For the Normal and regulating performance of Power Transformer, DGA analysis is most important and will provide control in different fault conditions.

Firstly In1928, Buchholz has represented the method of fault diagnosis due to failure in transformer oil and gases dissolved in transformer oil. Due to that type of Fault, oil-filled transformers realized that faults within a transformer would produce gases like C2H6, C2H4, C2H2, and CH4, remaining dissolved in oil. So that type of Fault could be detected using analysis of gases dissolved in transformer oil. DGA analysis provides Monitoring and conditioning of transformer due to which it is easy to distinguish faults like PD (partial discharge), corona, thermal heating, and arcing.

For analyzing transformer performance and Monitoring, DGA is considered the best method, and nowadays it is useful because it has several advantages like:- Advanced warning of developing faults, Status checks on new and repaired units and it also provides Convenient scheduling of repairing and maintenance during fault or overload condition in transformer operation.

The use of DGA analysis in the transformer will provide conditioning, Monitoring, reliability, and smooth operation of the oil-filled transformer. Now in the next section, we can discuss DGA analysis methods used in transformer conditioning & monitoring.

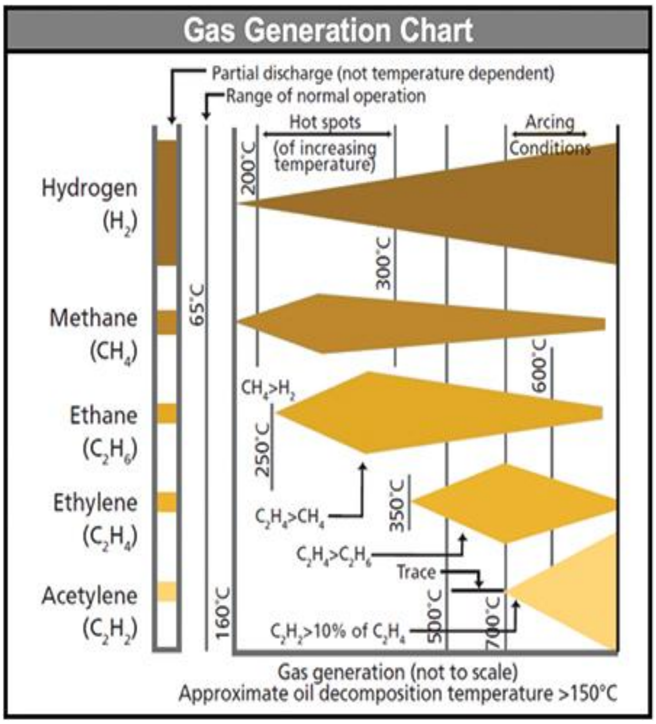

Fig.1- Gas Generation Chart

Fault diagnosis of power transformers are required for the reasons:-

I. Early detection of incipient faults:
- ✓ Avoid catastrophic outage
- ✓ Provide a basis for economical repair decision

II. Efficiency and Management:
- ✓ Maintenance management based on the measurement and trend analysis
- ✓ Aging process and residual life under control

The main aim and essential goal of Monitoring and diagnostic during operation is continually operating the transformer and accurately diagnosing the transformer's current condition and capability during any uncertain fault condition. This control will provide an alert just in time that quickly provides maintenance action as, and when required, the equipment remains useful.

II. SELECTION OF POWER TRANSFORMERS

The system engineer must include several primary considerations to select and design the best voltage to supply power to both present and future loads economically. Some of these are:

I. Safety It is desirable to achieve a high degree of equipment safety and the personnel working on power transformers and the adjoining area.

II. Reliability Power transformers must give a high degree of reliability even in stipulated operating conditions during its stipulated service span of at least 40 years within working specifications. Power transformers are designed and manufactured to meet reliability and offer trouble-free service.

III. Maintenance Power transformers regular maintenances are required to ensure reliable service throughout its life, putting back a transformer that has broken down into satisfactory working conditions in a minimum possible life and keeping the maintenance cost minimum. Thus transformer needs routine, corrective, preventive, proactive, and emergency maintenances during its service life.

IV. Voltage regulation there are possibilities of frequent overloads and exceptional overloads in the working of power transformers. Thus under any overload conditions, the power transformers should maintain high voltage regulation to keep the output voltage constant.

V. Initial investment every utility chooses to keep its economy at the priority. Thus, every manufacturer must keep the cost of a power transformer in competitive limits and keep other required specifications within the ranges.

VI. Simplicity in operation, each user develops his function needs appropriate to his requirements. Utilities also would want to operate power transformers with ease for the entire life of it. Thus simplicity in operation of power transformer becomes prime important.
VII. The overall system economics Starting from design, manufacturing, installation, maintenance, repair, and overhauls (if needed) involve economy. However, continuity of power supply is required from any transformer. The total cost of a transformer can be considered the assured annuity for the transformer's estimated life obtained from a capital sum invested.

III. NECESSITY OF FAULT DIAGNOSIS

Generally speaking, the term observance describes an essential parameter measure with threshold alarms. The term medicine indicates the addition of refined analysis; there is a spread of tools out there to judge transformers' condition. They will be separated into ancient DGA diagnostic strategies that have seen widespread use for transformers from so many different situations during nontraditional approaches that vary from processes set out to be wont to procedures still within the analysis stage. Fault diagnosis of power transformers are required for the reasons:

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IV. BENEFITS OF FAULT DIAGNOSIS

Some of the benefits of the fault diagnosis of any equipment, in general, are as follows:
1. Within Time Measurements of all parameters
2. Sensing of the fault gases in transformer operation
3. Predictive decision making for Fault
4. Reducing the outages of parameters
5. Accurate, predictable, and reliable maintenance schedules for transformers
6. Prevention of significant failure and destruction of protection equipment
7. Reduced maintenance cost
8. The results provide a quality control feature, limiting the probability of destructive failures

Types of Faults

Due to DGA analysis in transformer, there are different types of fault identification is done through proper research. According to the variation of Gases value of % variation will effects the Discharge and Thermal faults which are classified as given below:-
Partial Discharge (PD) – The corona discharge in the transformer oil will create PD effects in the oil-filled transformer, and energy discharge also occurs.
Discharges of Low Energy (D1) – This Fault will occur in oil due to the large carbonized punctures or carbon particles in the oil, which affects the performance of oil/paper.
Discharges of High Energy (D2) – This Fault will occur in oil due to extensive destruction and carbonization of oil in the transformer.
Thermal Fault (T1) – This type of Fault will occur below 300 °C in oil.
Thermal Fault (T2) – This type of Fault will occur above 300 °C & below 700 °C in oil.
Thermal Fault (T3) – This type of Fault will occur above 700 °C in oil.

Abbreviations	Descriptions
PD	Partial Discharges
D1	Discharges of Low Energy
D2	Discharges of High Energy
T1	Thermal Fault, t < 300 °C
T2	Thermal Fault, 300 °C < t <700 °C
T3	Thermal Fault, t > 700 °C

Fig.2-Types of Fault

V. DISSOLVED GAS ANALYSIS (DGA)

It is helpful for the detection of early faults and most used technique currently every day. DGA involves the following steps [1]. The first step is to take the Sample of oil from the unit and extract the oil's dissolved gases. The second step is to see the gas concentrations and analyze them by diagnostic strategies to search out the oil faults.

Most of the DGA diagnostic tools used these days are found within the IEEE C57.104 standard or IEC 60599 guides and supported these two standards used in different national and international to solely discuss those tools found within the IEEE and IEC guides.

DGA Analysis Methods

I. Conventional Methods:-

- ✓ Key Gas Method
- ✓ Doernenburg Ratio Method
- ✓ Rogers Ratio Method (RRM)
- ✓ Duval Triangle Method

II. Machine Learning Methods:-

- ✓ Fuzzy Logic Method
- ✓ ANN Method
- ✓ SVM Method
- ✓ Basient Method

Key Gas Method

The Key Gas method is based on the number of fault gases released from the insulating oil at varying temperatures in the transformer. Figure 4 summarizes the key gases and their fault indications.

Key Gas Method (IEEE Std. C57.104-2008)		
Key Gas	Fault Type	Typical Proportions of Generated Combustible Gases
C_2H_4	Thermal oil	Mainly C_2H_4; Smaller proportions of C_2H_6, CH_4, and H_2; Traces of C_2H_2 at very high fault temperatures
CO	Thermal oil and cellulose	Mainly CO; Much smaller quantities of hydrocarbon; Gases in same proportions as thermal faults in oil alone
H_2	Electrical Low Energy Partial Discharge	Mainly H_2; Small quantities of CH_4; Traces of C_2H_4 and C_2H_6
H_2 & C_2H_2	Electrical High Energy (arcing)	Mainly H_2 and C_2H_2; Minor traces of CH_4, C_2H_4, and C_2H_6; Also CO if cellulose is involved

Figure 4 Key Gas Method

Figure 5 indicates these key gases and their relative proportions to indicate the four general types of faults.

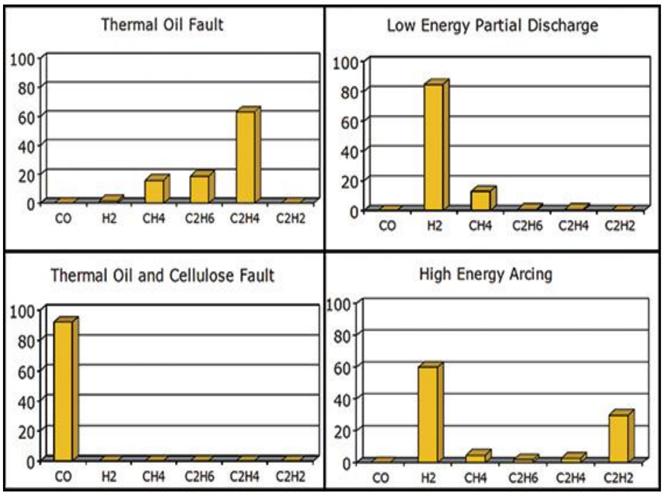

Figure 5 Key Gas Proportions

Doernenburg Ratio Method (DRM)

The Doernenburg method can be found in the IEEE C57.104-1991 guide, as shown in Figure 6. When this criterion is met, four possible ratios can be calculated if they contain the critical gas of concern. Figure 8 shows the proposed fault diagnostics is based on the ranges of the four ratios.

Concentration of Dissolved Gas	
Key Gas	L1 Concentrations (ppm)
Hydrogen (H_2)	100
Methane (CH_4)	120
Carbon Monoxide (CO)	350
Acetylene (C_2H_2)	35
Ethylene (C_2H_4)	50
Ethane (C_2H_6)	65

Figure 6 DRM method analysis

Rogers Ratio Method (RRM)

The Rogers Ratio method evolved from the Doernenburg method and is used the same way. Instead of needing significant concentrations of the key gases, the RRM can be used when the concentrations exceed the values listed in Figure 6; values for the three gas ratios, corresponding to suggested diagnostic cases, are shown in Figure 7.

Ratios for Key Gases – Rogers Ratios Method				
Case	Ratio 2 (R2) C_2H_2/C_2H_4	Ratio 1 (R1) CH_4/H_2	Ratio 3 (R3) C_2H_4/C_2H_6	Suggested Fault Type
0	<0.01	<0.1	<1.0	Normal
1	≥1.0	≥0.1, <0.5	≥1.0	Discharge of low energy
2	≥0.6, <3.0	≥0.1, <1.0	≥2.0	Discharge of high energy
3	<0.01	≥1.0	<1.0	Thermal fault, low temp <300 °C
4	<0.1	≥1.0	≥1.0, <4.0	Thermal fault, <700 °C
5	<0.2	≥1.0	≥4.0	Thermal fault, >700 °C

Figure 7 RRM Method analysis

VI. DUVAL TRIANGLE METHOD FOR DISSOLVED GAS ANALYSIS

In the 1970s, it was identified that the gas ratio methods have a disadvantage that some DGA results may not fall within the ratio codes. Hence, the diagnosis could remain unresolved. To overcome this problem, a graphical method was proposed by Duval in 1974. Within the Triangle, there are six (6) potential fault zones covering partial discharges, electrical faults that correspond to the increasing energy levels of gas formation, as shown in Figure.8

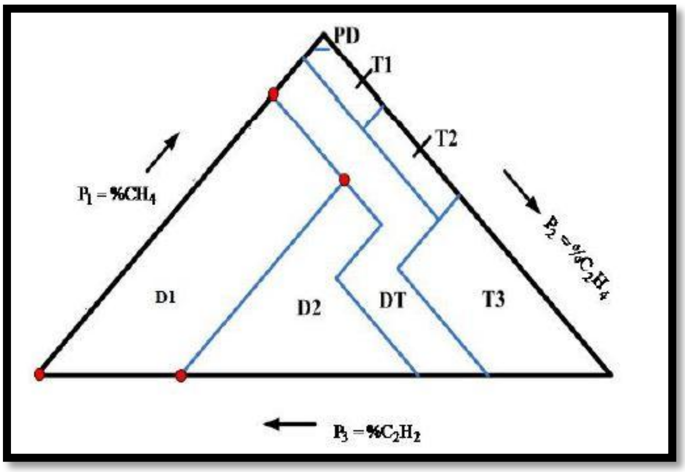

Figure-8: Duval Triangle Method representation of three types of fault zones

These gas concentrations are calculated and then plotted along the three sides of a triangle diagram using the following ratios:

- $\%CH_4 = (CH_4/CH_4+C_2H_2) \times 100$
- $\%C_2H_4 = (C_2H_4/CH_4+C_2H_4+C_2H_2) \times 100$
- $\%C_2H_2 = (C_2H_2/CH_4+C_2H_4+C_2H_2) \times 100$

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 <300^0C	Evidenced by paper turning brownish
T2	Thermal fault 300^0C-700^0C	formation of carbon particles, Carbonization of paper
DT	Combination of Electrical and Thermal	Discharges of low energy, pinholes

TABLE-1: DUVAL TRIANGLE DETECTABLE POSSIBLE FAULTS

From a percentage of P1 (such as point D), draw a parallel line to BC. Hence Figure-8 shows a Sample of the point shown in a triangle for the above example of gas concentrations.

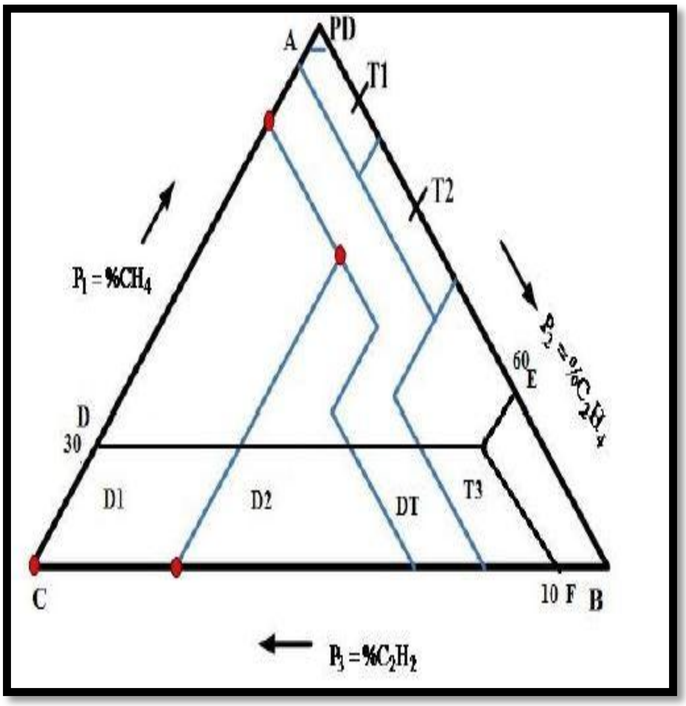

Figure-9: Sample of fault zone point showed in a Duval Triangle Method

Duval Triangle Fault Zones Coordinates

To focus on distinctive zones of the Duval Triangle, we need to characterize a polygon for each one zone. As indicated in Figure-9, Approximately 200 plus inspected fault cases in service were used to develop the Triangle.

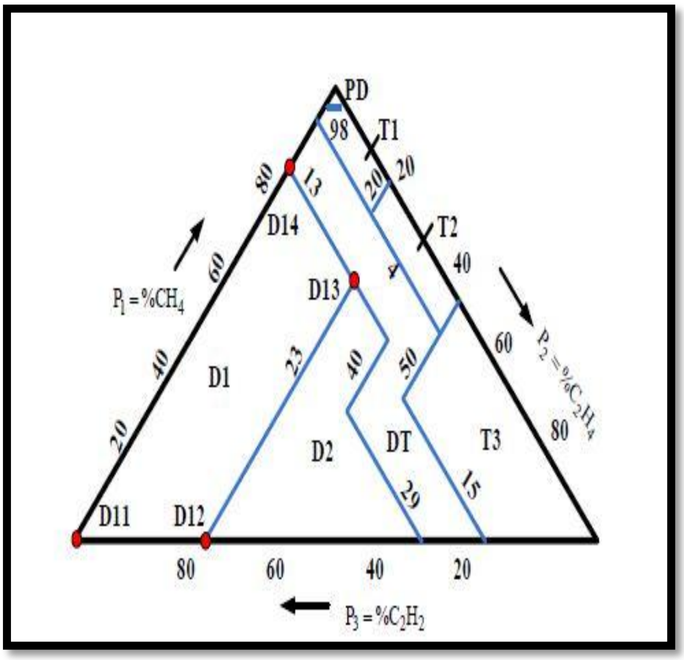

Figure-10: Different fault zone coordinates representation of Duval Triangle

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

TABLE-2: DUVAL TRIANGLE TRIANGULAR COORDINATES

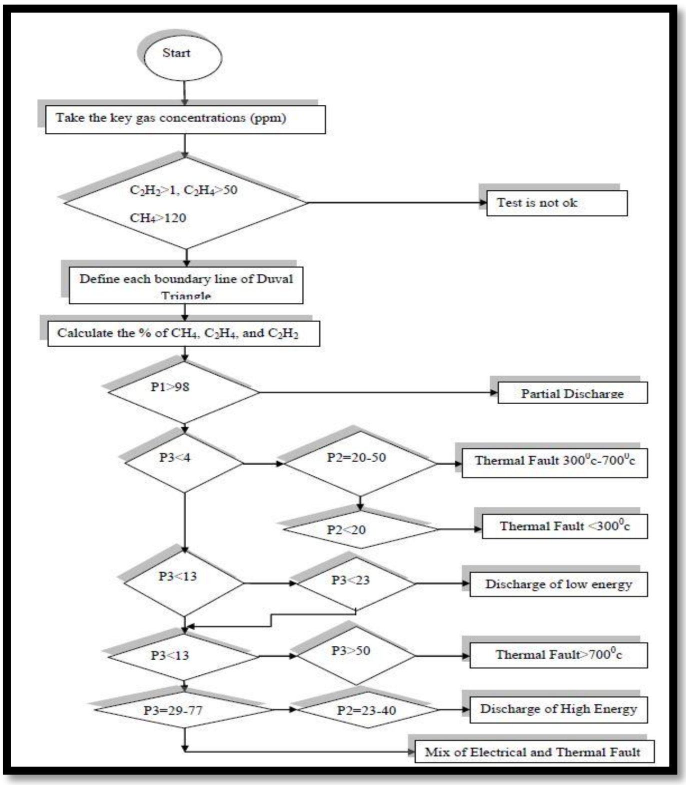

Figure-11 Flow chart of Identification of % CH4, %C2H4 and %C2H2 gases present in Transformer oil using Duval Triangle Method

Software Implementation to Duval Triangle

A MATLAB program is developed to implement the Duval Triangle; it gives a visual display of all fault zones with different colors.

Result and Discussions

The same sample input data used in the critical gas method shown in Table-1, Duval Triangle Method, is shown in Figure-12.

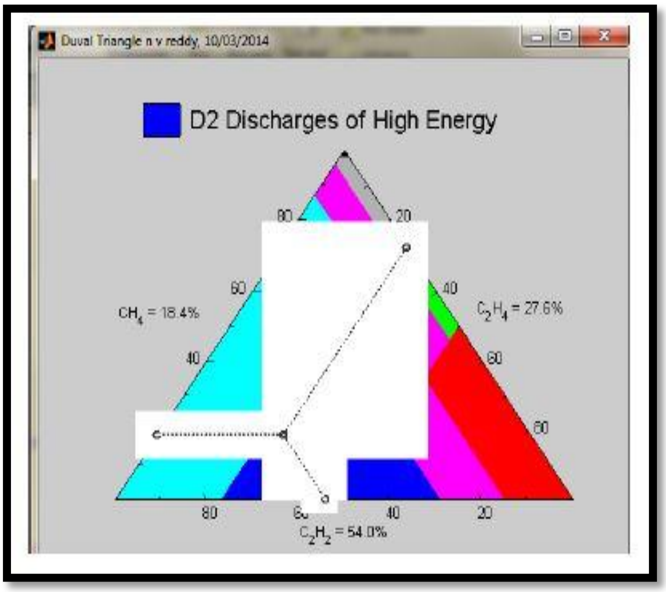

Figure-12: Result window of Duval Triangle Method using MATLAB

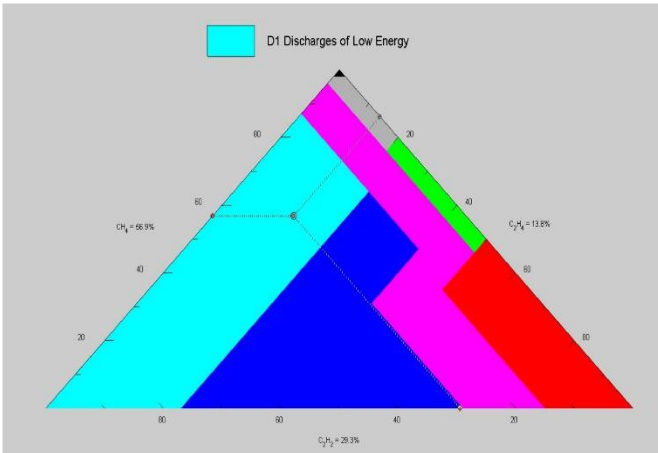

Fig.13- Discharge of Low Energy

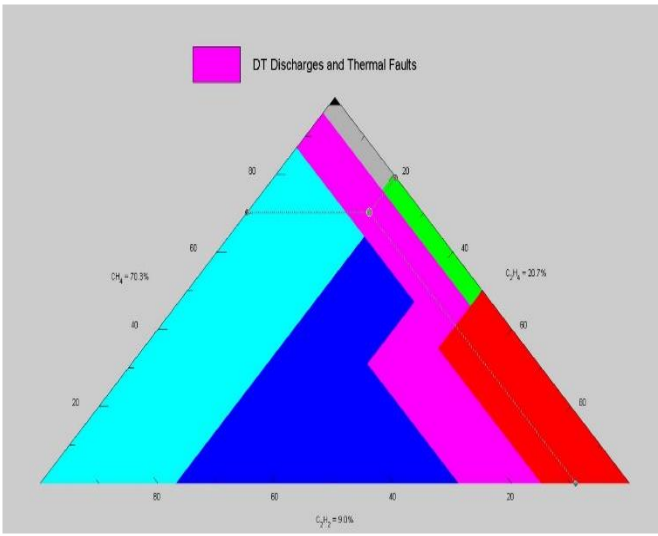

Fig.14- Discharge of Thermal Limits

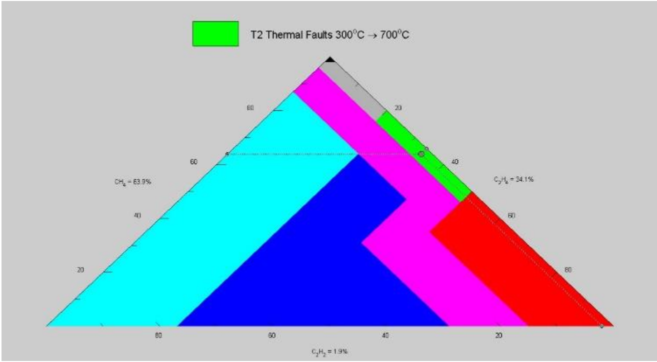

Fig.15- Thermal Limits Increased from 300°c to 700° C

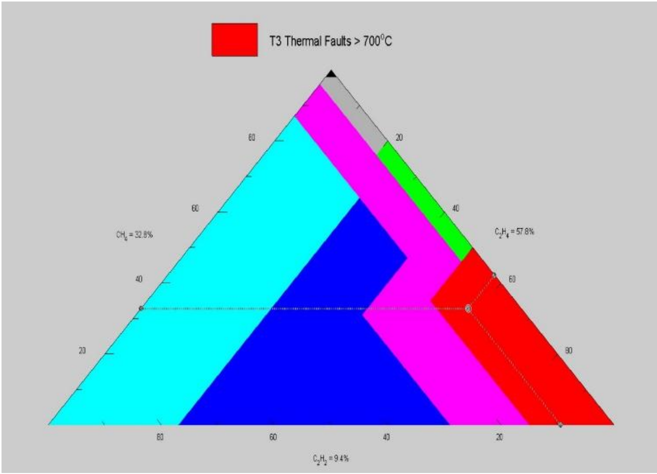

Fig.16 Thermal Fault Condition

Sr. No.	CH4 value (%)	C2H4 value (%)	C2H2 value (%)	Type of Fault
1.	56.9%	13.8%	29.3%	Discharge of Low energy
2.	70.3%	20.7%	9.0%	Discharge of Thermal Limits
3.	63.9%	34.1%	19%	Thermal Fault 300°c to 700° C
4.	32.8%	57.8%	9.4%	Thermal Fault above

From the Duval triangle simulation result, we can say that Gases CH4, C2H2, and C2H4 have been changed for different % value according to the different types of fault conditions identified like Low/High energy discharge and Temperature faults.

The different Fault types have been identified using Duval Triangle. The only limitation with this conventional method is that we can't make other variable parameters control like advanced control methods like AI techniques and Machine learning algorithms.

The Duval Triangle justifies the fault conditions with changes in CH4, C2H2 and C2H4 Dissolved gases in transformer oil.

Machine Learning

A branch of artificial intelligence, concerned with the design and development of algorithms that allow computers to evolve behaviors based on empirical data. As intelligence requires knowledge, computers must acquire knowledge.

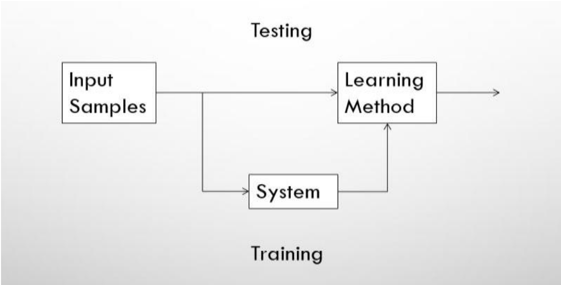

Fig.17.-Learning system model

ANN Implementation for DGA Analysis

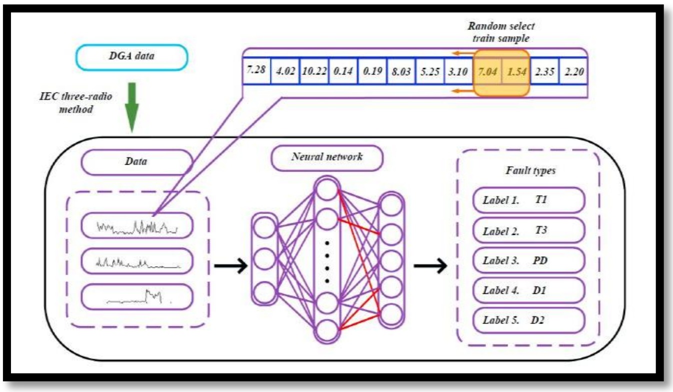

Fig.18 Power transformer fault diagnosis using ANN

In this project, we tend to plan a machine learning-based approach for fault identification of electrical power devices. The planned technique used the synthetic neural network (ANN) to construct the fault identification model. For several years there was no on-paper sound rule for coaching multi-layer ANN, and thus, the applications of ANN were severely restricted. A two-layer feed-forward network is shown in Fig. It consists of a variety of neurons connected by links divided into two layers.

A set of inputs is applied from the outside or previous layer. A corresponding weight w increases every of those. The add of the weighted inputs and therefore the bias .b. forms the information .n. to the transfer/activation operate "F." Neurons could use any differentiable, monotonic increasing transfer functions to get their outputs.

Simulation Results of ANN Techniques

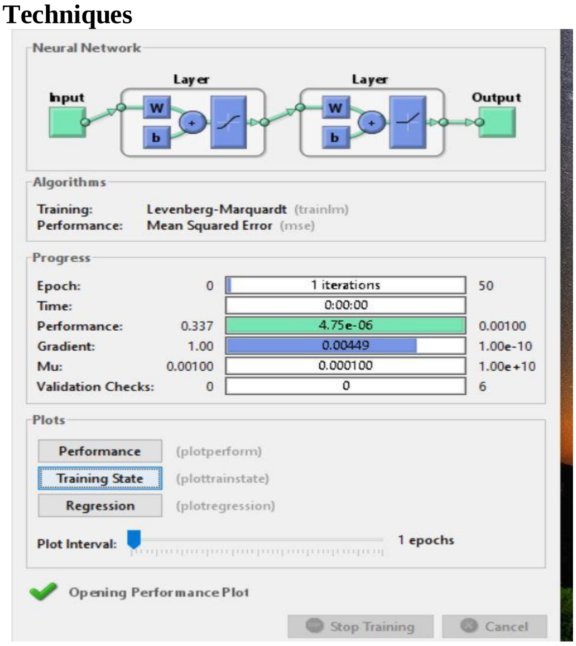

Fig.19 ANN Implementation for Case Study-I

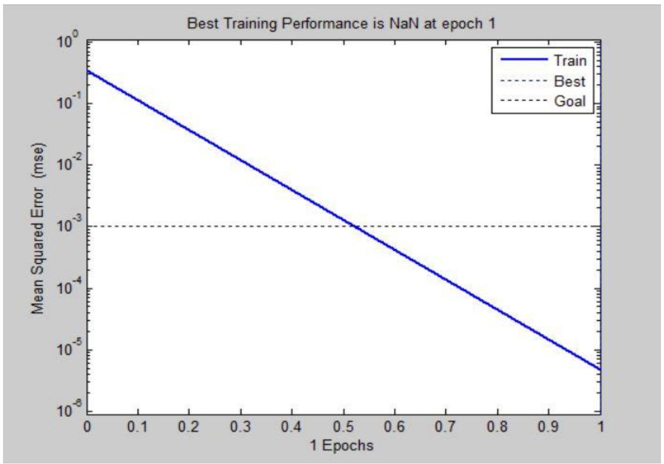

Fig.20- Performance Analysis of DGA for Case Study-I

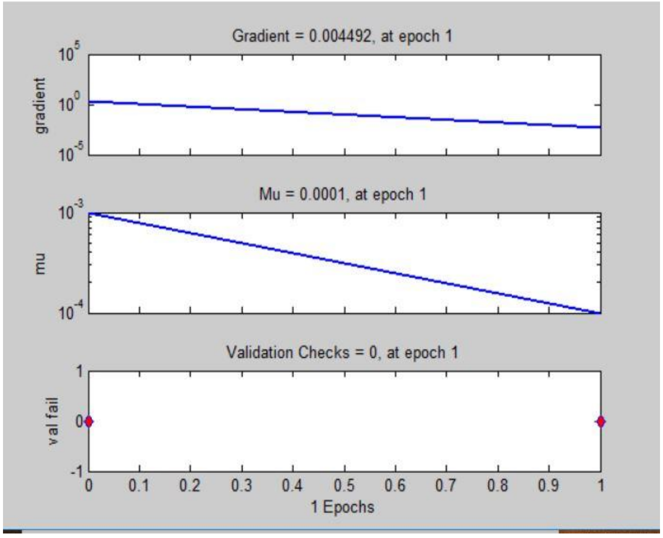

Fig.21 Parameters Variation for Case Study-I

Input	[%CH4 %C2H6 %C2H2]
Output	Faults [1 2 3 4 5 6 7]
Maximum Input	100%, 100%, 100%
Maximum Output	0.1%, 0.1%, 0.1%
Training Function	Levenberg-Marquardt
Epochs	50
Performance	Mean Square Errors (MSE)
Number of Neurons	2

Table 3: Parameters for ANN method

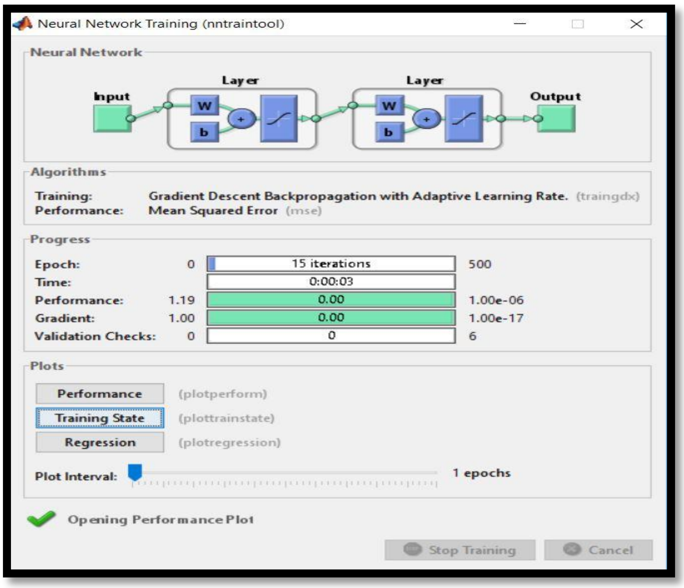

Fig.22- ANN Implementation for DGA Analysis Case Study-II

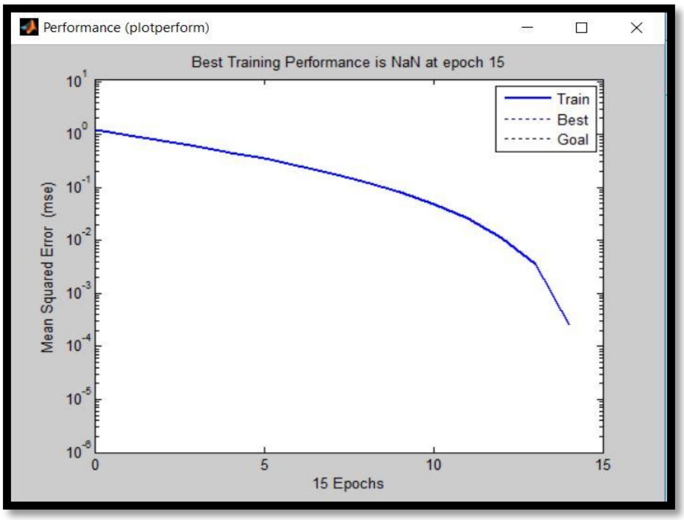

Fig.23- Validation performance chart for Case Study-II

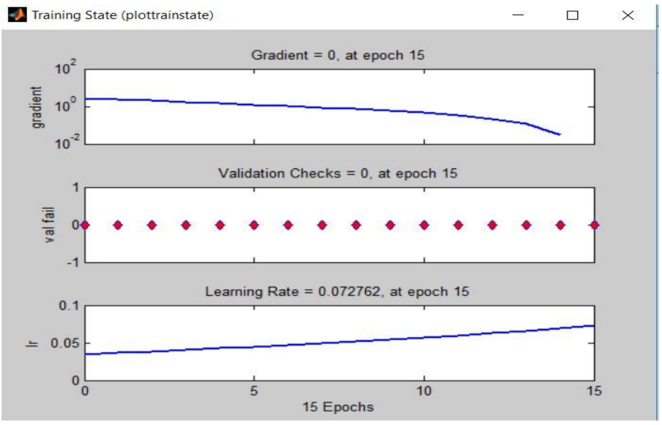

Figure.24- Mu and Gradient plot for Case Study-II

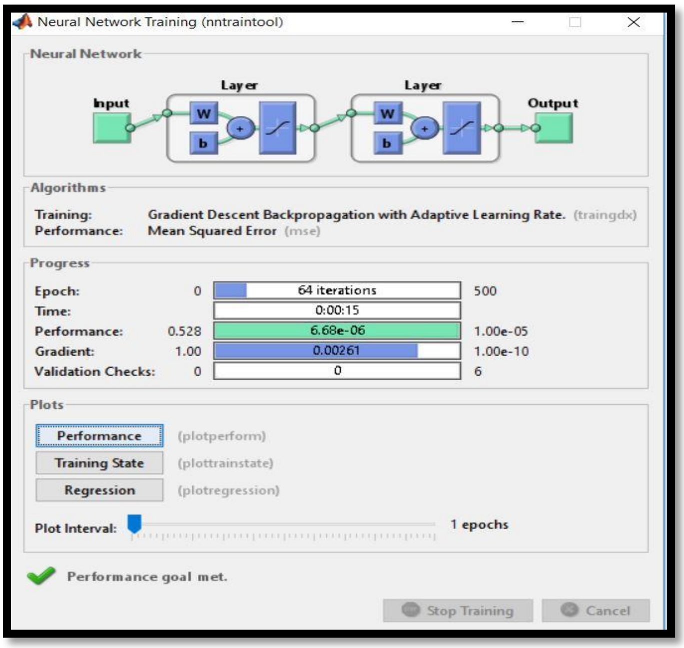

Fig.25- ANN Implementation for DGA Analysis
Case Study-III

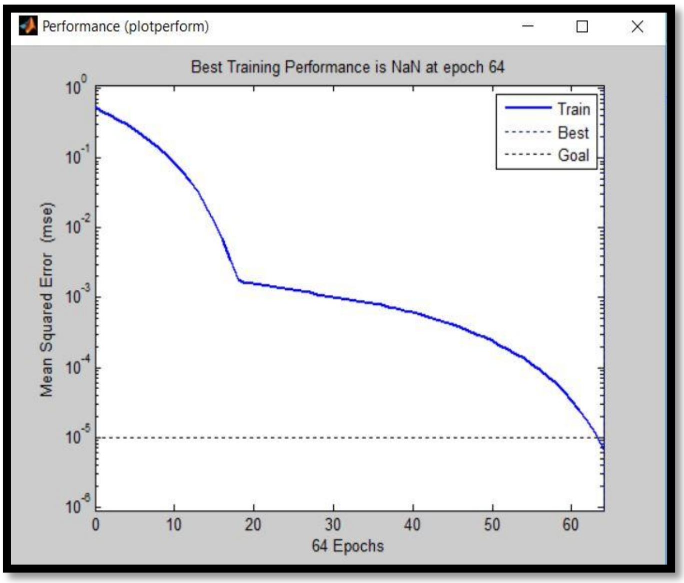

Figure.26- Validation performance chart for Case Study-III

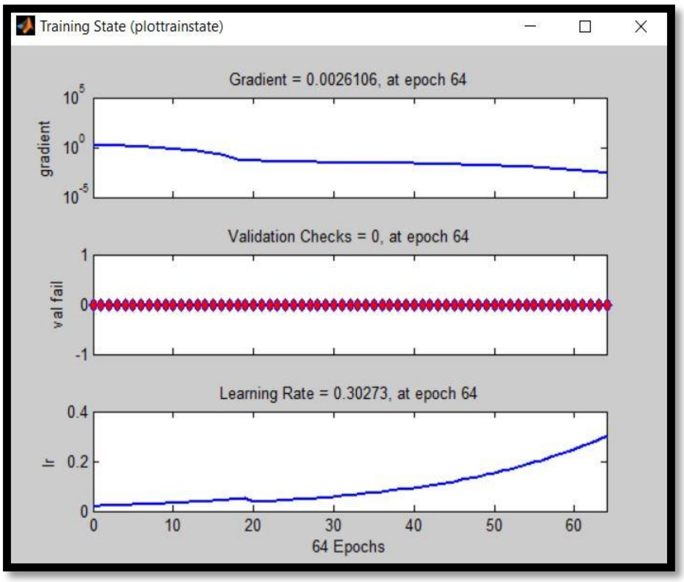

Figure.27- Mu and Gradient plot for Case Study-III

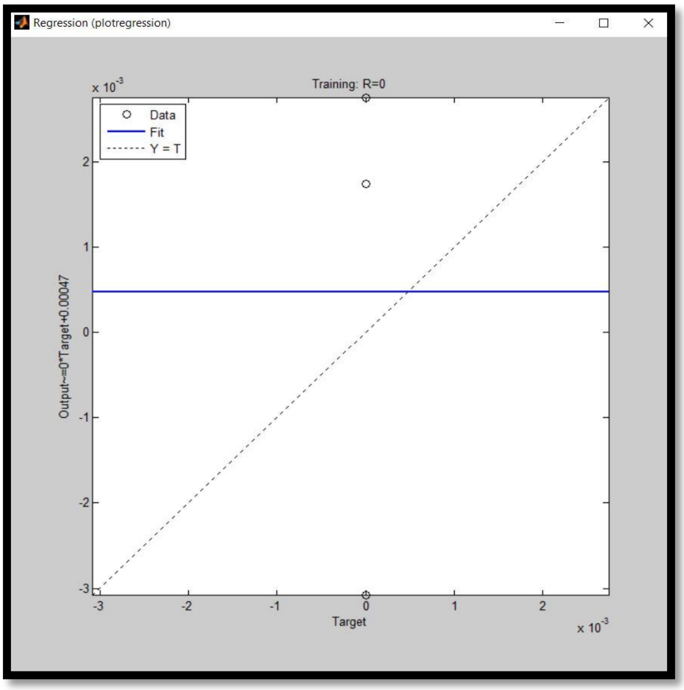

Figure.28- Target plots for Case study-III

SUMMARY OF SIMULATION RESULTS

- Simulated results with artificial neural network approaches on the Duval triangle are compared with fault diagnosis Simulation results.
- It is found that the artificial neural network approach will give better results than actual fault diagnosis report results using Duval Triangle. Further, it is observed that ANN provides fast and accurate results compared to Duval results.
- The main benefit is that using the ANN technique; we can perform the DGA analysis for different conditions and parameters; it has a wide range of applications.

VII. CONCLUSION

This work's primary purpose is to represent the DGA analysis of power transformers using different control methods. The condition-based analysis of DGA has developed using other control methods. A brief review is also described in this paper of all controlling techniques. Matlab simulation's simulation results have been successfully done through the Duval Triangle method as a conventional control method. ANN & Bayer's classifier method was developed as a machine learning control method. The simulation results show the better regulation of Machine learning methods compared to the conventional control method.

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Dr. Mihir K Patel, et. al. "Simulation of DGA Analysis for Power Transformer Using Advanced Control Methods." *International Journal of Engineering Science Invention (IJESI)*, Vol. 10(03), 2021, PP 53-68. Journal DOI- 10.35629/6734