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Development of Graphic User Interface for a Comprehensive Analysis of Dissolved Gas in Transformer Oil

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Abstract: Generally, the site location does not have additional transformer backup in case of maintenance or breakdown. In this study, Dissolved Gas Analysis (DGA) was used to measure the condition of oil-immersed by measuring the gas in parts per million (ppm) according to the IEC 60599 and IEEE C 57-104TM standards. It determines whether a transformer in service is ageing normally and in good condition, or if it is developing faults such as hot spots, arcing, overheating, or partial discharge. Therefore, App Designer MATLAB was used in developing a Graphical User Interface (GUI) for DGA interpretation in transformer oil with the suggested electrical test. The aims of this research are to analyze the DGA result based on Duval Triangle (DT) and Duval Pentagon (DP) analyses as well as develop a table of transformer maintenance guidelines based on the DGA's fault diagnosis. The DGA interpretation by DT and DP results showed that stray gassing oil is faulty due to the high production of gases such as hydrogen, methane, and ethane in oils. Therefore, according to maintenance guidelines, the stray gassing test (on the oil samples) must be taken immediately. To sum up, in this paper, the development of the GUI for DT and DP based on DGA interpretation provides the best results of maintenance and diagnostic techniques to determine the condition of transformers and electrical test action to be taken.

Keywords: Transformer, Dissolved Gas Analysis (DGA), App Designer MATLAB, Duval Triangle (DT), Duval Pentagon (DP), Maintenance Guideline

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1. Introduction

Large power transformers are major power system equipment where it is needed for the transmission and distribution of voltage. It maintains a low voltage, high current circuit on one side of the transformer, and a high voltage, low current circuit on the opposite side of the transformer. Oil from transformers that have been in operation for more than 30 years is still common in many areas specifically in the United States. Hence a test was conducted on the insulating oil of the transformer, which gives a tool for analyzing the operational state of the electrical apparatus called DGA [1].

The insulating oil in power transformers consists of a mixture of transformer oil and impregnated cellulose solids. It uses the amounts of different gases dissolved in the transformer oil owing to degrade the oil and paper insulating [2]. Oil-immersed power transformers are subject to a variety of thermal and electrical stresses, which can be studied using DGA [3]. It is also required to improve the devices used for gas detection in order to obtain a sufficient number of characteristic gas samples. DGA is used to detect incipient transformer faults, it offers advanced detection of incipient fault conditions leading to almost all the failure modes of transformer faults can help prevent further damage.

Duval Triangle (DT) and Duval Pentagon (DP) methods are some of the ways to interpret the DGA using graphical presentation. This approach used created from existing IEC 60599 and IEE 57.104 databases [4]. DT interpretations represent the relative percentage of three hydrocarbons (CH4, C2H4 and C2H2). DP representation, the relative percentages of the five main hydrocarbon gases such as H2, CH4, C2H6, C2H4 and C2H2 are the five basic hydrocarbon gases dissolved in oil that are commonly used in DGA operations. [3].

Transformer electrical testing is a key part of any maintenance program. The most critical test for liquid insulation is a yearly DGA. Overheating of the transformer insulation, overloading, liquid overheating, partial discharge (corona), or arcing can be detected by analyzing the oil's gas composition. Therefore, a practical transformer maintenance guideline was developed to verify the continuous integrity of the transformer unit at periodic intervals of time.

This study's goal is to analyze DGA results based on DT and DP analyses in order to create a table of transformer maintenance recommendations based on the DGA's fault diagnosis and a graphical user interface (GUI) for the DGA interpretation guidelines. Hence, the software that implements DT and DP Interpretation has not been developed. By utilizing MATLAB App Designer, the results of dissolved gas analysis can be found automatically completed with the suggested diagnostic table test.

This research is focused on developing software for DT and DP interpretation by designing and programming a graphical user interface (GUI) function in MATLAB software. DGA oil results from a local plant transformer based in Johor were selected for this study, and it is important to analyze a minimum of three outcomes in order to ensure that our findings are consistent and not influenced by chance factors which in this case are the sampling date from March, August and December of 2016. To investigate a solution for problem diagnosis so that we can establish preventative maintenance schedules, the analysis will be carried out with the help of DT and DP interpretation.

2. Materials and Methods

This part briefly overviews the project workflow as well as the development of the process of the research. It consists of two parts of progression which are a graphical user interface (GUI) implementation and an actual result Dissolve Gas Analysis (DGA) from a local plant based on formula implementation.

2.1 Graphical User Interface (GUI) using MATLAB

The GUI will be developed via App Designer available in MATLAB version R2021b. App Designer makes it possible for non-technical individuals to design high-quality apps. The workflow will begin by launching the App Designer, which is included in MATLAB. Then, under the design view tab, the GUI layout is created by dragging and dropping the components required for the desired GUI. Then, in the code view editor tab, specify the task of each component by inserting the coding. After that, run the developed GUI. If an error occurs, troubleshooting is needed to resolve it. Save the app if everything is working properly.

2.2 Duval Triangle

To understand the dissolved gases created in mineral immersed transformers, Michel Duval devised the Duval Triangle method (DTM) in 1974. For the classification of different types of faults, this method exclusively utilizes C2H2, C2H4, and CH4 [4]. The calculated gas concentration ratios are plotted into the Duval Triangle. The pointing zone represents the fault type, which may happen in the transformers.

Generally, the DT as seen in Figure 1, demonstrates the seven-section problem zone in the Duval Triangle. The DT has identified five triangles for DGA interpretation, each with its own set of terminology. However, the DT 3 for transformers filled with non-mineral oil is excluded from this research because mostly Malaysia's power system is powered by mineral oil-filled transformers.

2.2.1 Duval Triangle 1

To understand the dissolved gases created in mineral immersed transformers, Michel Duval devised the Duval Triangle method (DTM) in 1974. For the classification of different types of faults, this method exclusively utilises C2H2, C2H4, and CH4 [4]. The calculated gas concentration ratios are plotted into the Duval Triangle. The pointing zone represents the fault type, which may happen in the transformers. The Triangle coordinates corresponding to DGA results in ppm can be calculated as follows,

$$\%Ethylene, C_2H_4 = \frac{C_2H_4}{C_2H_4 + CH_4 + C_2H_2} \times 100\% \tag{1}$$

$$\%Methene, CH_4 = \frac{CH_4}{C_2H_4 + CH_4 + C_2H_2} \times 100\% \tag{2}$$

$$\%Acetylene, C_2H_2 = \frac{, C_2H_2}{C_2H_4 + CH_4 + C_2H_2} \times 100\% \tag{3}$$

where each gases concentrations in ppm respectively.

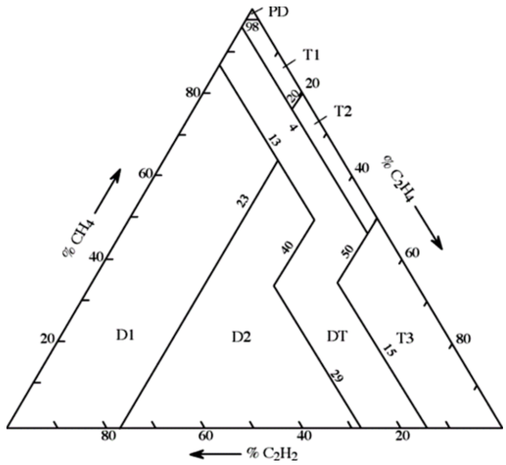


Figure 1: The Duval Triangle 1 for transformer filled with mineral oil

The DT 1 approach was shown to be very effective in detecting the most common type of defect in mineral oil-filled transformers in service.

2.2.2 Duval Triangle 2

The Duval Triangle 2 (DT 2) is designed for mineral oil-filled Load Tap Changers (LTCs) as shown in Figure 2. The DT 2 applies to conventional, compartment-type LTCs in which arc breaking in the oil is the primary mode of operation [5]. The identification of fault zones indicated in Figure 2. The gases C2H4, CH4, and C2H2 will be used as input data for DT 2. The gas percentages of C2H4, CH4, and C2H2 are calculated on the basis,

$$\%Ethylene, C_2H_4 = \frac{C_2H_4}{C_2H_4 + CH_4 + C_2H_2} \times 100\% \quad (4)$$

$$\%Methene, CH_4 = \frac{CH_4}{C_2H_4 + CH_4 + C_2H_2} \times 100\% \quad (5)$$

$$\%Acetylene, C_2H_2 = \frac{,C_2H_2}{C_2H_4 + CH_4 + C_2H_2} \times 100\% \quad (6)$$

where each gas's concentration is measured in parts per million.

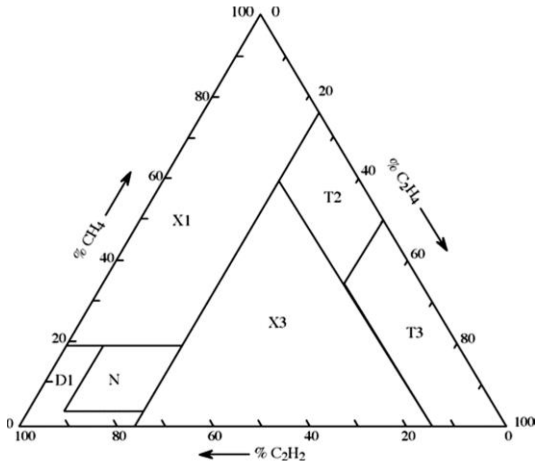


Figure 2: The Duval Triangle 2 for LTCs of the oil type

Because of the risk of contamination and the unpredictability of laboratory results, the DT 2 fault diagnostics should not be performed in LTCs if C2H2 and C2H4 concentrations are less than 10 ppm. An LTC's metallic parts retain some of the oil that has been removed and replaced with fresh oil when the old oil is extracted, evaporated, and the amount of extracted oil is measured [5].

2.2.3 Duval Triangle 4

The Duval Triangles 4 (Figure 3) for low-temperature faults in transformers have been developed to remove uncertainties when DGA results are close to the boundary between zones PD and T1. Furthermore, several types of oils on the market are prone to "stray gassing," or the formation of gases unexpectedly at low temperatures such as 80 to 200°C [6].

$$\%Hydrogen, H_2 = \frac{H_2}{H_2 + CH_4 + C_2H_6} \times 100\% \quad (7)$$

$$\%Methene, CH_4 = \frac{CH_4}{H_2 + CH_4 + C_2H_6} \times 100\% \quad (8)$$

$$\%Ethane, C_2H_6 = \frac{C_2H_6}{H_2 + CH_4 + C_2H_6} \times 100\% \quad (9)$$

where each gases concentrations in ppm respectively.

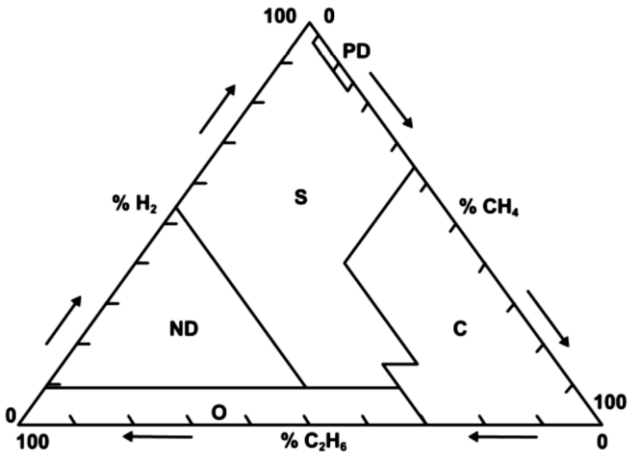


Figure 3: The Duval Triangle 4 for low-temperature faults in transformers filled with mineral oil

The triangle in Figure 3 is made up of three low-energy gases (H2, CH4, and C2H6) [5]. It is based on the results of laboratory tests for transformer failures and stray gassing. In transformers, stray gases may emerge in the PD, T1, or T2 zones, which may hinder the detection of these faults. It is recommended that DT 4 only be used in conjunction with DT 1 for defects that have been detected by DT 1 as potentially having PD, T1, or T2 causes.

2.2.4 Duval Triangle 5

For thermal faults, the Duval Triangle 5 (DT 5) is used to gain further information regarding faults classified as T2 or T3 type thermal faults using the DT 1 and to confirm faults accompanied with uncertainties after utilising the DT 4 [4]. The triangle will utilize the 3 so-called "temperature gases" which is C2H4, CH4, and C2H6 will be used for the calculation in DT 5. After the relative percentage of each gas are obtain, it can be plotted in the assigned DT 5. The fault can be determined by the intersection of the three lines fall in the fault zones.

$$\%CH_4 = \frac{x}{x+y+z} \times 100\% \tag{10}$$

$$\%C_2H_4 = \frac{y}{x+y+z} \times 100\% \tag{11}$$

$$\%C_2H_6 = \frac{z}{x+y+z} \times 100\% \tag{12}$$

where each gas's concentration is measured in parts per million.

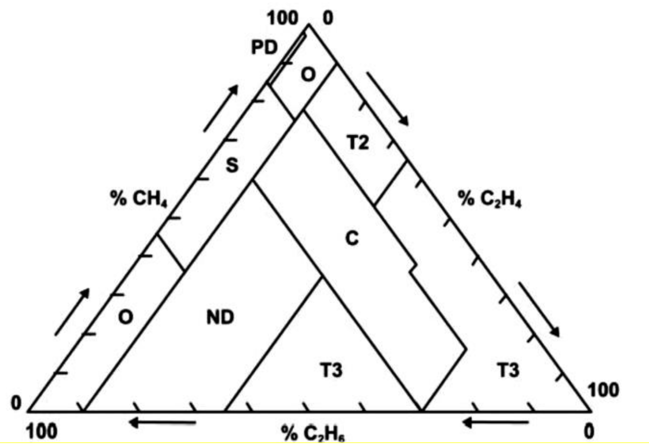


Figure 4: The Duval Triangle 5 for low-temperature faults in mineral oil filled transformers

After employing the Duval Triangle 4, the "Duval Triangle 5 for low-temperature faults in transformers" can be used to corroborate fault attributions that are still in doubt [5]. The gases produced similar corona partial discharges and low-temperature oil fault. Compared to sparking partial discharges of the D1 type, the temperature of cold plasma discharges, which occur in the gas phase, is fairly low as shown in Figure 4.

2.3 Duval Pentagon

The Duval Pentagon 1 and Duval Pentagon 2 (DP 1 and DP 2), which use the five essential gases (H2, CH4, C2H6; C2H4, C2H2) positioned at the apices of the pentagon, represent a new technique of interpreting the DGA. [4]. This method was intended to overcome difficulties that the Duval Triangles method could not solve. In this paper, the pentagons are presented for applications in mineral oils (Pentagons 1 and 2) only. This is because the other pentagons, such as ester oils (Pentagons 3 for FR3, Rapeseed, Sunflower, Midel) does not fulfil Malaysia's power system standard which is powered by mineral oil-filled transformers.

2.3.1 Duval Pentagon 1

The Duval Pentagon 1 (DP 1) use the same gases which are C2H4, CH4, C2H2, H2 and C2H6. The DP 1 is visualized in Figure 5. 12. For single fault cases, DP 1 can be used in combination with DT 1 [7]. This only sufficient when the main interest of the analysis is for identification of one of the 6 basic types of faults and stray gassing. The calculation for the percentage of gases for DP 1 (C2H4, CH4, C2H2, H2 and C2H6) are shown in equation below respectively.

$$\%Ethylene, C_2H_4 = \frac{C_2H_4}{C_2H_4 + CH_4 + C_2H_2 + H_2 + C_2H_6} \times 100\% \quad (13)$$

$$\%Methane, CH_4 = \frac{CH_4}{C_2H_4 + CH_4 + C_2H_2 + H_2 + C_2H_6} \times 100\% \quad (14)$$

$$\%Acetyelene, C_2H_2 = \frac{C_2H_2}{C_2H_4 + CH_4 + C_2H_2 + H_2 + C_2H_6} \times 100\% \quad (15)$$

$$\%Hydrogen, H_2 = \frac{H_2}{C_2H_4 + CH_4 + C_2H_2 + H_2 + C_2H_6} \times 100\% \quad (16)$$

$$\%Ethane, C_2H_6 = \frac{C_2H_6}{C_2H_4 + CH_4 + C_2H_2 + H_2 + C_2H_6} \times 100\% \quad (17)$$

where each gases concentrations in ppm respectively.

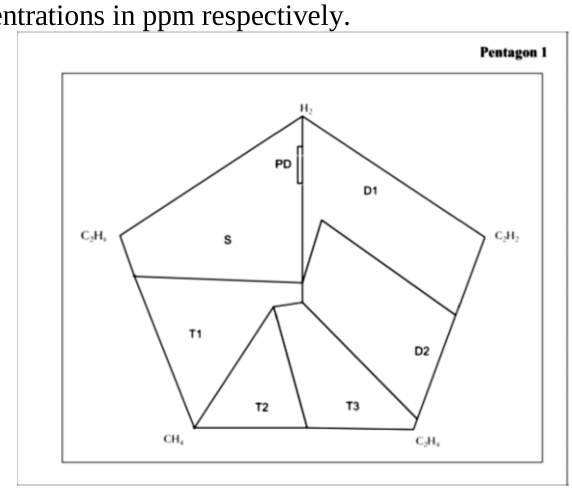


Figure 5: The Duval Pentagon 1 for the 6 basic types of faults

2.3.2 Duval Pentagon 2

The Duval Pentagon 2 (DP) 2 is shown in Figure 6. This pentagon is used when more subtypes of thermal faults, such as T3-H, C, and O, need to be identified [7]. DP 2 is relatively the same with DP 1. The DP 2 has three basic electrical faults, PD, D1 and D2, as well as four more precisely defined thermal faults, T3-H, C, O, and S, which are used in DT 4 and 5 [4]. The percentages of gases for DP 2 (C2H4, CH4, C2H2, H2, and C2H6) are calculated as given in the equation below,

$$\%Ethylene, C_2H_4 = \frac{C_2H_4}{C_2H_4 + CH_4 + C_2H_2 + H_2 + C_2H_6} \times 100\% \quad (18)$$

$$\%Methane, CH_4 = \frac{CH_4}{C_2H_4 + CH_4 + C_2H_2 + H_2 + C_2H_6} \times 100\% \quad (19)$$

$$\%Acetyelene, C_2H_2 = \frac{C_2H_2}{C_2H_4 + CH_4 + C_2H_2 + H_2 + C_2H_6} \times 100\% \quad (20)$$

$$\%Hydrogen, H_2 = \frac{H_2}{C_2H_4 + CH_4 + C_2H_2 + H_2 + C_2H_6} \times 100\% \quad (21)$$

$$\%Ethane, C_2H_6 = \frac{C_2H_6}{C_2H_4 + CH_4 + C_2H_2 + H_2 + C_2H_6} \times 100\% \quad (22)$$

where each gas's concentration is measured in parts per million.

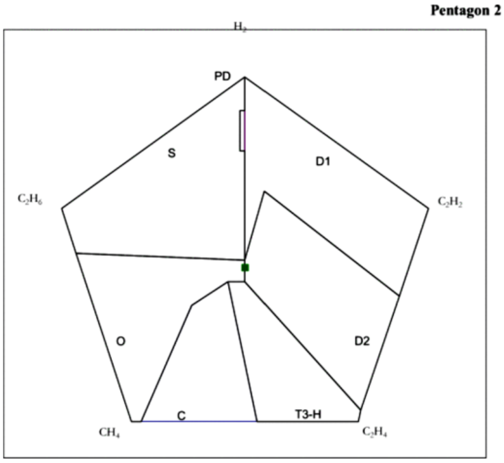


Figure 6: The Duval Pentagon 2 for the 4 sub-types of thermal faults

3. Results and Discussion

The transformer nameplate used for case study is shown in Table 1. For each application, a thorough comprehension of the transformer's nameplate data is necessary. Nameplates provide useful information can be used to understand energy use, discover compatible or more efficient maintenance for equipment, and troubleshoot problems.

The nameplate is similar to a birth certificate in certain ways. This specification is for a three phase 50HZ, 22/0.433kV, oil immersed, naturally air-cooled transformer with off load tap changer for 2MVA transformer.

Table 1: 22/0.433kV Nameplate

NAMEPLATE DATA	
MANUFACTURING	ABB
DATE MANUFACTURING	2012
KVA	2000
PRIMARY	22000 V
SECONDARY	433 V
KILOGRAMS	5600
EQUIP TYPE	TRANSFORMER
TRANS CLASS	ONAN
IMPEDENCE	5.87%
PHASE/CYCLE	3/50 Hz

LIQUID TYPE	OIL
LITRES LIQUID	1059

Since 2016 to 2022 the oil sample collection was carried out to make sure whether a transformer is operating normally, especially if there is no past dissolved gas history, or the transformers have been in operation for a long time.

Table 2 presented the data of ten collection oil sample for 22/0.433kV Oil Transformer. When mineral oil maintains normal dissolved gas values, the legends imply that there is no incipient transformer malfunction. When the value exceeds the usual limit, the sample frequency should be raised since exceeding the normal limit shows that the transformer has some minor problems. Some further activities must be made before the issue becomes critical in order to avert critical faults in other equipment. When the reading exceeds the action limit, it indicates that a critical situation has occurred, and the transformer should be removed from service.

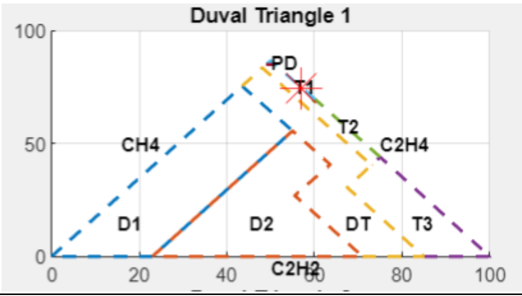
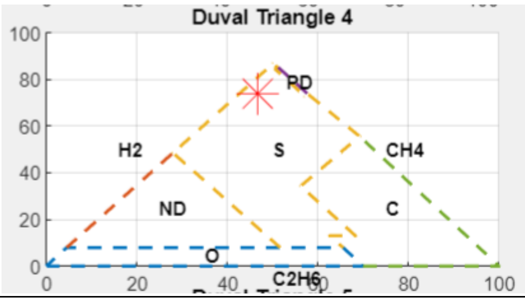
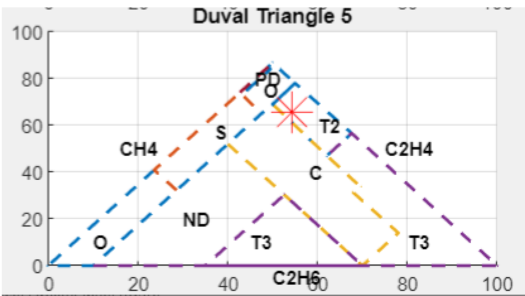
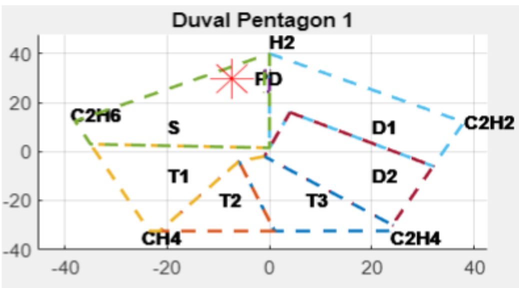
Table 2: Sampling DGA Result for 22/0.433kV Oil Transformer

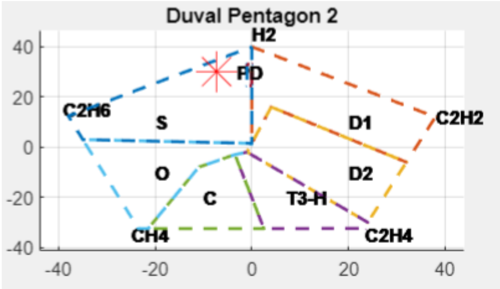
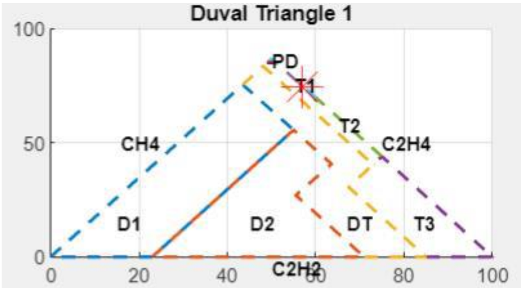
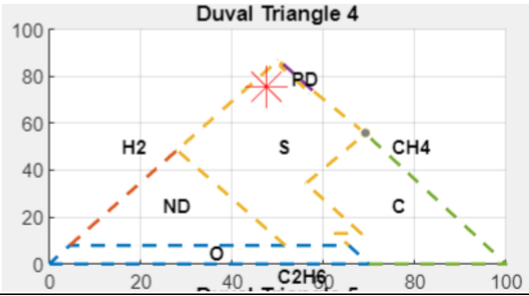
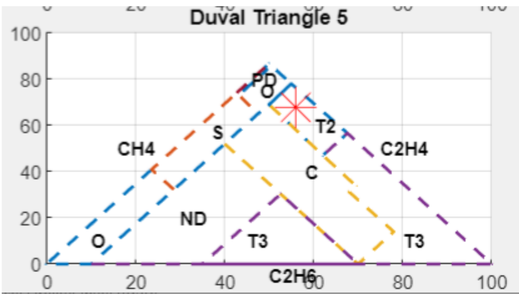
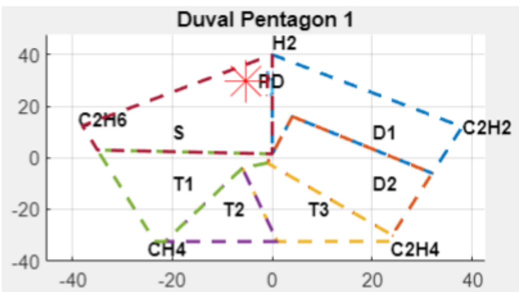
Sampling Date	H_2 (0<1800ppm)	O_2	N_2	CH_4 (0-1000ppm)	CO (0-1400ppm)	CO_2 (0-10000ppm)	C_2H_6 (0-150ppm)	C_2H_4 (0-200ppm)	C_2H_2 (0-35ppm)
March 2016	751	21836	66479	37	164	954	94	6	ND
August 2016	946	16319	6208	43	176	1093	96	7	ND
December 2016	955	12409	4720	45	173	1113	78	6	ND
March 2017	13	7336	35419	4	75	164	6	ND	ND
June 2017	35	1249	41899	3	92	499	9	ND	ND
December 2017	56	14999	58028	6	288	987	10	2	ND
January 2019	32	14541	53566	59	118	1069	60	1	ND
January 2020	69	15614	53661	14	660	2542	10	5	ND
January 2021	101	14794	44480	11	744	3405	9	4	ND
January 2022	185	10915	92317	12	1114	4496	7	5	ND

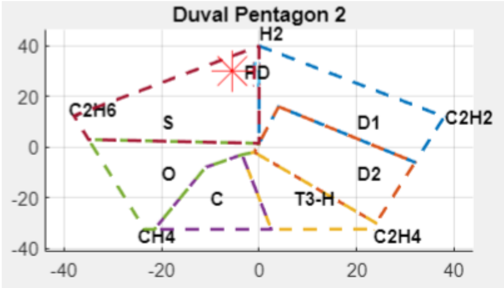
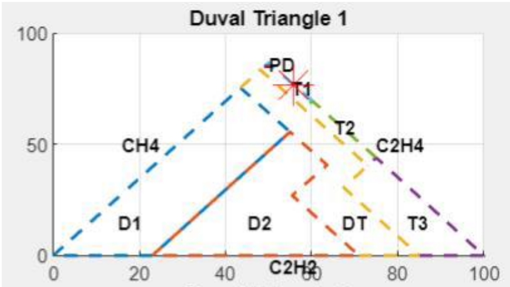
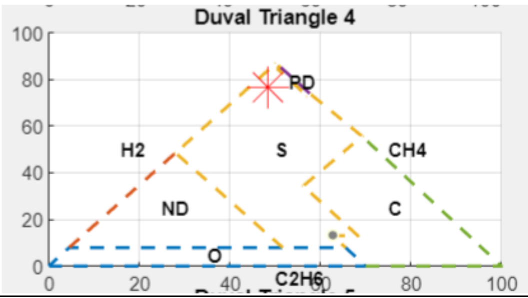
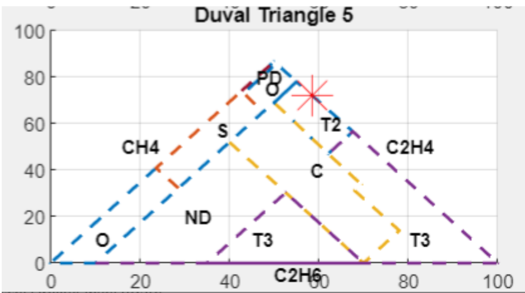
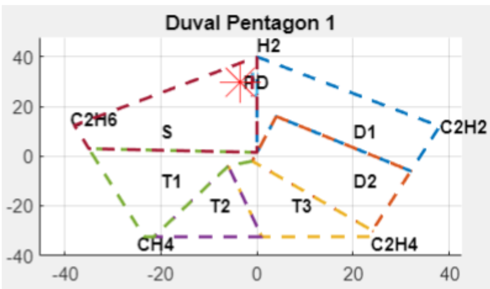
GREEN	Normal limits (acceptable)
YELLOW	Exceed Normal Limits (caution)
RED	Extreme limits (unacceptable)

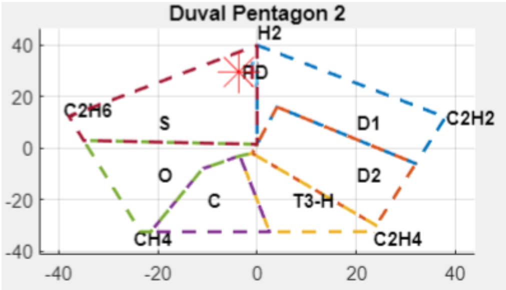
As shown in Table 3, for the case of 22/0.433kV, 2MVA oil-filled transformer was analyze using GUI for DT and DP, and the results are provided in this part. However, only 3 sampling date since on March 2016, August 2016 and December 2016 will be discussed instead of total 10 sampling date for this case.

Table 3: Faults identified by the GUI

Sampling Date	Faults	GUI Result
March 2016	DT 1	
	DT 4	
	DT 5	
	DP 1	

<table>
<tr><th>Sampling Date</th><th>Faults</th><th>GUI Result</th></tr>
<tr><td></td><td>DP 2</td><td>
</td></tr>
<tr><td rowspan="5">August 2016</td><td>DT 1</td><td>
</td></tr>
<tr><td>DT 4</td><td>
</td></tr>
<tr><td>DT 5</td><td>
</td></tr>
<tr><td>DP 1</td><td>
</td></tr>
</table>

Sampling Date	Faults	GUI Result
	DP 2	
December 2016	DT 1	
	DT 4	
December 2016	DT 5	
	DP 1	

Sampling Date	Faults	GUI Result
	DP 2	

Next, the transformer status can be determined using DGA interpretation techniques, which take into account the relative concentrations of various gases in oil samples (measured in parts per million, or ppm). These techniques include empirical approaches such as IEC 60599, IEEE 57.104 and graphical methods such as the Duval Triangle and Duval Pentagon as presented in Table 4. Since the particular samples have been taken and analyzed from the sampling date of March, August and December of 2016 as shown in Table 4, it is now possible to identify dissolved gas components in service-aged fuels using the DGA test. This test determines the number of specific gases produced by a liquid-filled transformer in service. Many discoveries have been made in the field of diagnosing transformer systems for developing faults.

Table 4: The DGA Interpretation for 22/0.433kV Oil Transformer

Sampling Date	Exceed IEEE C57.104	Exceed IEC 60599	Duval Triangle 1	Duval Triangle 4	Duval Triangle 5	Duval Pentagon 1	Duval Pentagon 2
March 2016	YES	YES	Thermal Faults of Temperature <300C	Stray Gassing of Oil<300C	Thermal Faults **in Oil Only** of High Temperature 300C<T<700C	Stray Gassing of Oil<300C	Stray Gassing of Oil<300C
August 2016	YES	YES	Thermal Faults of Temperature <300C	Stray Gassing of Oil<300C	Thermal Faults **in Oil Only** of High Temperature 300C<T<700C	Stray Gassing of Oil<300C	Stray Gassing of Oil<300C
December 2016	YES	YES	Thermal Faults of Temperature <300C	Stray Gassing of Oil<300C	Thermal Faults **in Oil Only** of High Temperature 300C<T<700C	Stray Gassing of Oil<300C	Stray Gassing of Oil<300C

Therefore, predictive maintenance of transformers is an integral part of an annual total maintenance program. Although DGA is a major key to maintaining transformer health, it is still only of a complete protective maintenance plan. Therefore, a practical transformer maintenance guideline developed to verify the continues integrity of the transformer unit at periodic intervals of time. If a fault appears to be developing, then more frequent electrical tests may be scheduled to monitor this condition.

To summarize, the most accurate fault for these 3 sampling data dates determined is Stray Gassing of Oil<300C. This is because present of high combustion in common gases such H2, CH4 and C2H6. The DGA interpretation is success due to each DT utilized concentration of 3 gases from the DGA, meanwhile DP utilized concentration of 5 gases. The fault that identified by the GUI is advance warning of developing more faults that may lead to transformer failures.

Table 5: Summary faults identified by the GUI

Sampling Date	Faults				
	DT 1	DT 4	DT 5	DP 1	DP 2
March 2016	T1	S	T1	S	S
August 2016	T1	S	T1	S	S
August 2016	T1	S	T1	S	S
Suggested Electrical Test	• Check Transformer Cooling System • Frequency Domain Spectroscopy Test	Stray Gassing Test (on oil sample)	• Frequency Response Analysis Test • Turn Ratio Test	Stray Gassing Test (on oil sample)	Stray Gassing Test (on oil sample)

4. Conclusion

Detecting deterioration in insulation and oil, overheating, hot spots, partial discharge, and arcing is the first step in diagnosing a problem. The health of the transformer's oil is a decent indicator for its overall condition. The most important indicators are the individual and total combustible gas rates gas in parts per million (ppm) based on the IEC 60599 and IEEE C 57-104TM standards from the International Electrotechnical Commission (IEC).

Hence, App Designer MATLAB was used to develop a graphical user interface for a comprehensive analysis of dissolved gas (DGA) in transformer oil. Even while the most of DGA is still done in laboratories, the trend is toward online DGA monitoring, which enables for the detection and diagnosis of transformer defects throughout their service life. A direct outcome of DGA therefore offers sufficient information to diagnose the state of operation of the transformers. Thus in this paper, it emphasizes that manual and software implementations to interpret the faults in transformers by DT and DP method for DGA provide the best results for maintenance operation. Early detection of trouble can be repaired for appreciably less than it would cost if the incipient fault went undetected and was left to develop until warning is given by a Buchholz relay or other similar device.

For a clean bill of health, one needs a complete physical. The frequency of these tests influenced by many factors such as the type and class of the transformer, its importance, age, load, and history of operation. Scheduled outages should also be utilized as periods for testing to determine the nature of extent of the damage when a transformer has failed. The test's data can be used to predict possible problems and guide maintenance and replacement plans that are precisely targeted. Transformer electrical testing is a tried-and-true loss prevention strategy that should be incorporated in any condition-based predictive maintenance program.

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