

Development of Software for Duval Triangle and Pentagon Interpretation on Transformer Oil Dissolved Gas Analysis

Zukry Abdul Latiff¹, Mohd Fairouz Mohd Yousof^{1*}

¹Department of Electrical Engineering, Faculty of Electrical and Electronic Engineering,
Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

*Corresponding Author Designation

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Abstract: Duval triangle (DT) and Duval pentagon (DP) are methods to interpret the dissolved gas analysis (DGA) result of transformer oil. DGA is used to differentiate between normal and fault condition of the power transformer as it require a high degree of reliability. This is because any fault that occurred to the unit will bring a huge impact on power transmission system. Since transformers are in operation continuously, it is very important to avoid any accident by able to predict faults within them and conducting maintenance on the transformer's condition. DT utilized concentration of three gases from the DGA. On the other hand, DP utilized concentration of five gases. These concentrations are then interpreted by DT and DP methods. The interpretation would identify which fault occurs. This paper presents a comparison on the outcome of DT and DP analysis. The analysis is then presented in a standalone graphical user interface (GUI) software. Three case studies were presented based on three different transformers' DGA samples. The first cases gave out the same result for DT and DP interpretation. However, the other two cases had some differences in the result interpreted. The differences were shown in the result and discussion.

Keywords: Dissolved Gas Analysis, Duval Triangle, Duval Pentagon

1. Introduction

During energy transfer in the power transmission, power transformers require a high degree of stability and reliability as any fault that happened within power transformers will bring a huge impact on power transmission. Power transformers are getting older as time expand, it is very vital to avoid accident occur involving them by predicting faults within them and conducting maintenance based on correct knowledge of their present conditions.

Dissolved gas analysis (DGA) is widely used to detect incipient faults in oil-filled electrical equipment [1]. Hence, power transformers can be diagnostics by DGA because in power transmission, the transformer are filled with oil to avoid overheating. Internal faults in transformers generate 7 gases

Hydrogen (H₂), Acetylene (C₂H₂), Ethylene (C₂H₄), Methane (CH₄), Ethane (C₂H₆), Carbon Monoxide (CO) and Carbon Dioxide (CO₂) are dissolved in the insulating oil [2]. DGA is the oldest proven reliability method for detecting faults or other abnormalities within a transformer by evaluating and analyzing difference gases produced by flawed energy caused by such faults can be used to detect fault or other abnormalities that may occur within the power transformer [3].

Duval Triangle (DT) and Duval Pentagon (DP) methods are some of the ways to interpretate the DGA [4]-[5]. This paper will discuss more on how to develop the GUI software for DT and DP interpretation method using App Designer in MATLAB software [6]-[8]. The results for 3 cases from the DT and DP interpretation using the GUI software were compared with the results interpreted using Microsoft Excel provided from Michel Duval.

2. Materials and Methods

2.1 Method

Figure 1 shows the flowchart for the GUI software. Both DT and DP GUI software used this flowchart because the flow of the software was the same. The difference was in the process part whether interpreting using DT or DP.

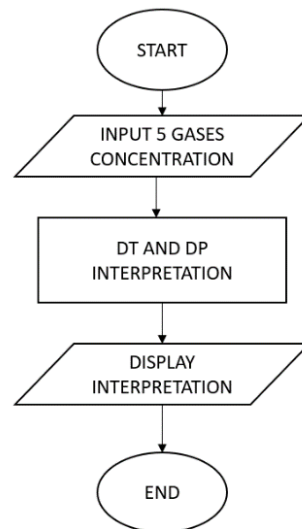


Figure 1: The flowchart for this project

The user need to input 5 gases concentration into the respective GUI software whether DT or DP. In DT GUI software, all 5 concentration were request as input so that user does not required to repeatedly input 3 concentration for each triangle. In DP GUI software, the input of 5 gases concentration were needed because DP interpretation used the total of 5 concentration of gases.

After the user input the required concentration, both GUI software would process the input according to DT and DP interpretation method. Then, the result for the interpretation would be shown by the each GUI software in a form of dot plotted on the cartesian plane in the boundaries of DT and DP fault zone.

2.2 Equation

DT 1 and 2 would use the same gases which are C₂H₄, CH₄ and C₂H₂ as their input data. The calculation for the gas percentage of C₂H₄, CH₄ and C₂H₂ are shown in equation Eq. 1, Eq. 2 and Eq. 3 respectively. that are used for DT 1 and 2 [1].

$$\% \text{ Ethylene, } C_2H_4 = \frac{C_2H_4}{C_2H_4 + CH_4 + C_2H_2} \times 100\% \quad \text{Eq. 1}$$

$$\% \text{ Methene, } CH_4 = \frac{CH_4}{C_2H_4 + CH_4 + C_2H_2} \times 100\% \quad \text{Eq. 2}$$

$$\% \text{ Acetylene, } C_2H_2 = \frac{C_2H_2}{C_2H_4 + CH_4 + C_2H_2} \times 100\% \quad \text{Eq. 3}$$

Next, DT 4 would use H_2 , CH_4 , and C_2H_6 for the percentage calculation. The calculation for the gas percentage for H_2 , CH_4 , and C_2H_6 are show *Eq.4*, *Eq.5* and *Eq.6* respectively.

$$\% \text{ Hydrogen, } H_2 = \frac{H_2}{H_2 + CH_4 + C_2H_6} \times 100\% \quad \text{Eq. 4}$$

$$\% \text{ Methene, } CH_4 = \frac{CH_4}{H_2 + CH_4 + C_2H_6} \times 100\% \quad \text{Eq. 5}$$

$$\% \text{ Ethane, } C_2H_6 = \frac{C_2H_6}{H_2 + CH_4 + C_2H_6} \times 100\% \quad \text{Eq. 6}$$

CH_4 , C_2H_4 , and C_2H_6 would be used for the calculation in DT 5. Equation *Eq.7*, *Eq. 8* and *Eq. 9* show the calculation for CH_4 , C_2H_4 , and C_2H_6 , respectively. After the relative percentage of each gases were obtain, it can be plotted in the assigned DT. The fault can be determined by the intersection of the three lines fall in the fault zones.

$$\% \text{ Methene, } CH_4 = \frac{CH_4}{H_2 + CH_4 + C_2H_6} \times 100\% \quad \text{Eq. 7}$$

$$\% \text{ Ethylene, } C_2H_4 = \frac{C_2H_4}{C_2H_4 + CH_4 + C_2H_2} \times 100\% \quad \text{Eq. 8}$$

$$\% \text{ Ethane, } C_2H_6 = \frac{C_2H_6}{H_2 + CH_4 + C_2H_6} \times 100\% \quad \text{Eq. 9}$$

Both DP 1 and 2 used the same gases which are C_2H_4 , CH_4 , C_2H_2 , H_2 and C_2H_6 . The calculation for the percentage of gases for DP 1 and 2 (C_2H_4 , CH_4 , C_2H_2 , H_2 and C_2H_6) are shown in *Eq. 10*, *Eq.11*, *Eq.12*, *Eq.13* and *Eq. 14*, respectively [4]. After the five percentages were obtain, it can be plotted on each respective gas axis.

$$\% \text{ Ethylene, } C_2H_4 = \frac{C_2H_4}{C_2H_4 + CH_4 + C_2H_2 + H_2 + C_2H_6} \times 100\% \quad \text{Eq. 10}$$

$$\% \text{ Methene, } CH_4 = \frac{CH_4}{C_2H_4 + CH_4 + C_2H_2 + H_2 + C_2H_6} \times 100\% \quad \text{Eq. 11}$$

$$\% \text{ Acetylene, } C_2H_2 = \frac{C_2H_2}{C_2H_4 + CH_4 + C_2H_2 + H_2 + C_2H_6} \times 100\% \quad \text{Eq. 12}$$

$$\% \text{ Hydrogen, } H_2 = \frac{H_2}{C_2H_4 + CH_4 + C_2H_2 + H_2 + C_2H_6} \times 100\% \quad \text{Eq. 13}$$

$$\% \text{ Ethane, } C_2H_6 = \frac{C_2H_6}{C_2H_4 + CH_4 + C_2H_2 + H_2 + C_2H_6} \times 100\% \quad \text{Eq. 14}$$

Then, the (x, y) coordinates of the centroid of these five points were calculated using *Eq.15* and *Eq.16*, where x_i and y_i are the coordinates of the five points, and C_x and C_y the (x, y) coordinates of the centroid. The fault could be determined by which fault zone does the centroid falls.

The *Eq.17* shows the calculation for the area, A of the irregular pentagon from the five points plotted in DP 1 and 2

$$C_x = \frac{1}{6A} \sum_{i=0}^{n-1} (x_i + y_{i+1})(x_i y_{i+1} - x_{i+1} x_i) \quad Eq. 15$$

$$C_y = \frac{1}{6A} \sum_{i=0}^{n-1} (y_i + x_{i+1})(x_i y_{i+1} - x_{i+1} x_i) \quad Eq. 16$$

$$A = \frac{1}{2} \sum_{i=0}^{n-1} (x_i y_{i+1} - x_{i+1} x_i) \quad Eq. 17$$

3. Results and Discussion

Three cases were analyzed using the developed GUI software for DT and DP. The results for each case are provided in this section. Figure 2 and Figure 3 show the user interface of the GUI software for DT and DP, respectively. The user interface (UI) for both software were quite similar to each other in which the user will need to input 5 gases concentration into the provided space. After filling up the input, the user can press the start button to produce the output of the GUI software. The output is indicated by the dot plotted in the respective DT 1, 2, 4 and 5, and DP 1 and 2. Each dot is located at a certain area or fault zone in the triangle or pentagon. Each zone is designated for each type of fault or condition. The fault zone definition is also included in the GUI to assist user in understanding the result.

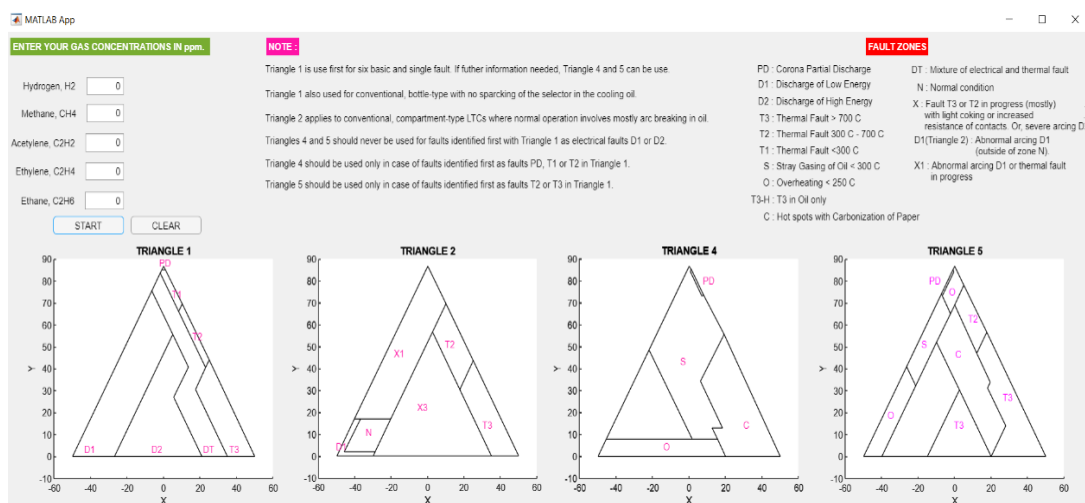


Figure 2: The developed GUI software for DT

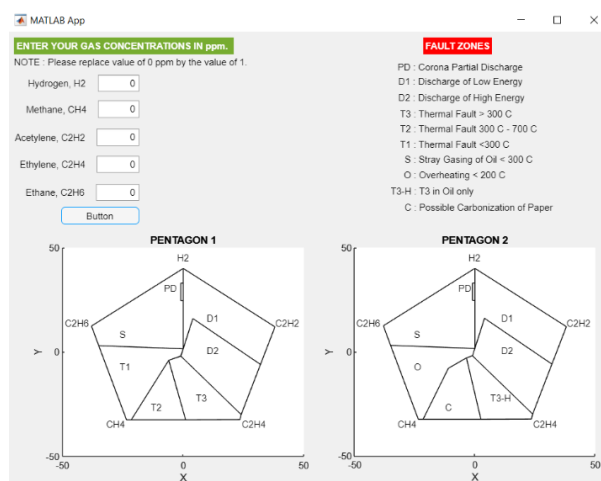


Figure 3: The developed GUI software for DP

Table 1 shown the fault identified for 3 cases using DT and DP interpretation using Microsoft excel. DT and DP interpretation for case 1 identified the fault Corona Partial Discharge (PD). In cases 2, DT method identified the fault PD using DT1 and Overheating under 250 °C (O) using DT4 and DT5. DT method identified the fault of Discharge of low energy (D1) using DT 1. DT method discussed that there is no need to proceed the interpretation with DT4 and DT5 if the fault identified by DT1 were D1, Discharge of high energy (D2) or Thermal fault over 700 °C (T3). DP interpretation also identified the fault of D1 for case 3.

Table 1: Summary of all the fault identified for the three cases using Excel

CASE	RESULT				
	DT1	DT4	DT5	DP1	DP2
1	PD	PD	PD	PD	PD
2	PD	O	O	S	S
3	D1	NOT APPLICABLE	NOT APPLICABLE	D1	D1

Table 2 shows the fault identified by DT and DP interpretation method using the developed GUI software. In case 1, the DT and DP GUI software identified the fault of PD by DT1, Stray gassing (S) by DT4, PD by DT5 and PD by both DP1 and DP2 respectively. In case 2, the DT GUI software identified the fault of PD by DT1 and O by DT4 and DT5. However, DP GUI software identified S as the fault by both DP1 and DP2. In case 3, DT GUI software identified the fault of D1 by DT1 hence, the result from DT4 and DT5 were not applicable. However, DP GUI software could not identify the fault for case 3.

Table 2: Summary of all the fault identified for the three cases using GUI software

Case	Result				
	DT 1	DT 4	DT 5	DP 1	DP 2
1	PD	S	PD	PD	PD
2	PD	O	O	S	S
3	D1	NOT APPLICABLE	NOT APPLICABLE	NO PLOT ON THE GRAPH	NO PLOT ON THE GRAPH

The first difference is in DT 4 for case 1. Result using excel give out the fault PD however, the GUI software give out the fault S. This error cause by the negative value of x-coordinate for the centroid by the GUI software. However, both coordinates of centroids have the same value of y-coordinate. The second difference is in DP 1 and 2 for case 3. The reason for this behaviour still unidentified.

4. Conclusion

The GUI software for DT and DP were successfully developed using App Designer MATLAB. However, there are issues of accuracy where in certain case the fault identified by the DT and DP software were not the same with the fault identified using Excel. In the future, the algorithm of the GUI software needed to be revised to get rid the inaccuracy issue. There will be an addition of conditional algorithm to the current algorithm to increase the accuracy of the GUI software developed.

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