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Implementation of Matlab in Analysis of D.G.A of Transformer Oil Through Duval Triangle

Vibhor Kumar Singh[1], Shweta Singh[2]

[1]*Research Scholar, Department of Electrical Engineering, Maharishi University of Information Technology Lucknow, Uttar Pradesh, India- 226013*

[2]*Assistant Professor, Department of Electrical Engineering, Maharishi University of Information Technology Lucknow, Uttar Pradesh, India- 226013*

***Abstract*—Dissolved Gas Analysis (DGA) is one of the most widely used methods for diagnosing the health of any oil filled transformer. The Duval Triangle Method is used to interpret the cause of fault occurred in any faulty transformer on the basis of three gases i.e. Methane (CH4), Ethylene (C_2H_4) and Acetylene (C_2H_2). In this research paper, efforts have been made to diagnose the DGA sample with help of MATLAB tool implementing Duval Triangle. In this process, the concentration of all the three gases shall be taken as input while output shall be revealed in various zones of Duval Triangle.**

***Index Terms*—Dissolved Gas Analysis (DGA), Duval Triangle Method Fault Diagnosis, MATLAB.**

I. INTRODUCTION

The Dissolved Gas Analysis is a process to find healthiness of Transformer oil. In this method concentration of gases are taken from Oil sample. Thereafter, data of concentration of gases are analyzed with various method such as (Key gas ratio, Roger's gas ratio method, Doernenburg gas ratio method and Duval Triangle method) to find the cause of fault or to check the healthiness of transformer. The Duval Triangle method is one of the best methods in analyzing the DGA data. The whole Duval Triangle interpretation is applied on merely their gases Methane CH_4, Ethylene C_2H_2 and Acetylene C_2H_2 [1]. A number of theories have been published in order to implement Duval Triangle method in MATLAB. In this research paper effort has been made to implement the Duval Triangle method in MATLAB which can be used in order to analyze DGA data.

II. STUDY OF FAULT ZONES IN DUVAL TRIANGLE

The double Triangle is equilateral triangle which is composed of 7 zones. Each zone represents type of fault and the reason of fault. These zones are described as follows:

i) PD Zone: any fault within this zone will be created as partial discharges. The reason of partial discharges maybe due to Corona or electrical spark. It is found that any lose connection inside the Transformer such as loose winding connections and loose core blessing also causes partial discharge.

ii) D2 zone: D2 zone represents discharges of high energy. The discharges of high energy occur mainly due to degradation or oxidation of paper/ oil insulation resulting carbon particle and sludge.

iii) D1 zone: D1 zone represents discharges of low energy. A low energy arcing induces pin holes and carbonized punctures in paper and decomposition of oil.

iv) DT zone: This zone consists of thermal and electrical fault.

v) T1 zone (T < 300 °C): This zone consists of thermal faults in which temperature is less than 300 °C. At this temperature the color of paper insulation turns brownish or it may have carbonized.

vi) T2 zone (700< T < 300 °C): When temperature inside the Transformer becomes greater than 300 °C but less than 700 °C the paper insulation become completely carbonate. It may cause carbon particles in oil.

vii) T3 zone (T > 700 °C): When temperature inside the Transformer increases above 700 °C excessive formation of carbon particle occurs in oil. Even the color of metals such as copper, steel, iron gets changed.

III. FAULT LOCATOR LOCI

The concentration of three key gases (Methane CH_4, Ethylene C_2H_2 and Acetylene C_2H_2) is taken in clockwise manner at three sides of Duval Triangle. The side of triangle representing maximum concentration of any gas shall be denoted in percentage. Therefore, the sides of equilateral triangle or the Dvual Triangle shall be 100%. If we consider concentration of Methane, Ethylene and Acetylene as x %, y % and z % percent in clock wise manner. A Fault locator point will be obtained by drawing a parallel line from the point on the sides of triangle representing concentration of gas. The line from point of gas concentration must be drawn parallel to that side of triangle which is previous to it.

Let concentration (in percent) of Acetylene (C2H2), Methane (CH4) and Ethylene (C2H4) are in terms of 'a', 'b' and 'c'. The line from side representing concentration of Methane CH_4 (x %) is parallel to side representing concentration of Acetylene C_2H_2 (z %). The intersection of all three parallel lines will provide a fault locator point. The fault locating Point (m, n) can be calculated from Figure-1.

m = b*Sin60

n = 100 – (a + b*Cos60)

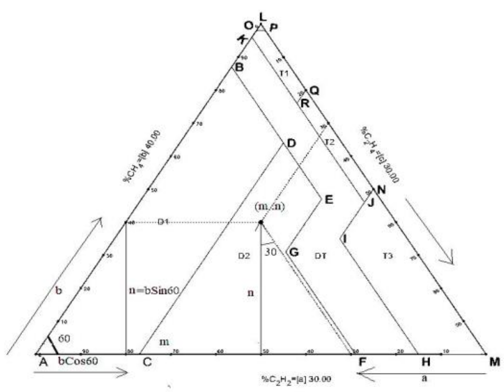

Figure 1: Fault locator point

The fault locator point would represent the zone of fault out of any of the seven zones, describing the reason of fault in transformer.

IV. BOUNDARIES OF FAULT ZONES

The Extreme coordinates of Zones of the fault in Duval Triangles are christened as A,B,C,D,E,F,G,H,I,J,K,L,M,N,O,P,Q and R. Point 'A' may be treated as origin and left corner of Duval triangle is placed at 'A'.

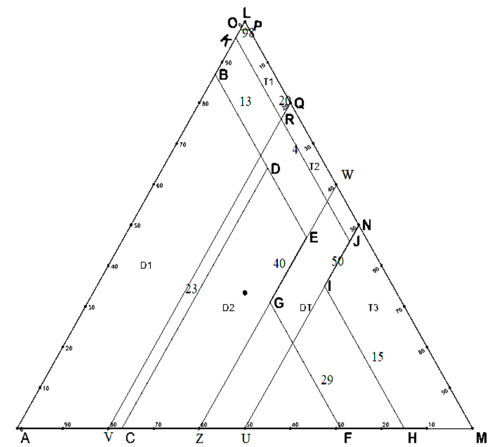

Figure-2: Calculations for coordinates

The value of these coordinates (in %) will be calculated with help of simple trigonometry calculations given as follows: -

1. For Point A: Consider it as a origin [x(1),y(1)] = (0,0).
2. For Point B :

AB= 100-13=87

x(2) = AB*Cos60 = 87*0.5 = 43.5

y(2)= AB*Sin60 = 75.344

[x(2), y(2)] = [43.5, 75.344]

3. For Point C :

AC= 23

x(3) = 23

y(3)= 0

[x(3), y(3)] = [23, 0]

4. For Point D :

CD= 100-23-13=64

x(4) = CD*Cos60+23 = 55

y(4)= CD*Sin60= 55.42562584

[x(4), y(4)] = [55, 55.42562584]

5. For Point E :

EZ= 60-13 = 47

x(5) = EZ*Cos60+40 = 63.5

y(5) = EZ*Sin60 = 40.7031939

[x(5), y(5)] = [63.5, 40.7031939]

6. For Point F :

AF= 100-29 = 71

[x(6), y(6)] = [71, 0]

7. For Point G :

ZG = WZ-WG=60-29 = 31

x(7) = ZG*Cos60+40 = 55.5

y(7) = ZG*Sin60 = 26.8467875

[x(7), y(7)] = [55.5, 26.8467875]

8. For Point H :

AF= 100-15 = 85

[x(8), y(8)] = [85, 0]

9. For Point I :

IU = NU-NI = 50-15 = 35

x(7) = IU*Cos60+50= 67.5

y(7) = IU*Sin60 = 30.31088913

[x(9), y(9)] = [67.5, 30.31088913]

10. For Point J :

JU = NU-NJ = 50-4 = 46

x(10) = JU*Cos60+50 = 73

y(10) = JU*Sin60 = 39.83716857

[x(10), y(10)] = [73, 39.83716857]

11. For Point K :

AK = 100-4 = 96

x(11) =AK *Cos60 = 48

y(11) = AK*Sin60 = 83.1384387

[x(11), y(11)] = [48 , 83.1384387]

12. For Point L :

AL = 100

x(12) =AL *Cos60 = 50

y(12) = AL*Sin60 = 86.602540378

[x(12), y(12)] = [50, 86.602540378]

13. For Point M :

AM= 100

[x(13), y(13)] = [100, 0]

14. For Point N :

NM = 50

x(14) = NM *Cos60 + 50 = 75

y(14) = NM*Sin60 = 43.30127018

[x(14), y(14)] = [75, 43.30127018]

15. For Point O :

AO = 100-2 = 98

x(15) = AO *Cos60 = 49

y(15) = AO *Sin60 = 84.8704895

[x(15), y(15)] = [49, 84.8704895]

16. For Point P :

AO = 100-2 = 98

x (16) = AO *Cos60+2 = 51

y (16) = AO *Sin60 = 84.8704895

[x (16), y(16)] = [51, 84.8704895]

17. For Point Q :

QM = 100-20 = 80

x (17) = QM *Cos60+20 = 60

y (17) = QM *Sin60 = 69.2820323

[x (17), y(17)] = [60, 69.2820323]

18. For Point R :

RV=QV-QR = 80-4 = 76

x (18) = RV *Cos60+20 = 58

y (18) = RV *Sin60 = 65.81793068

[x (18), y(18)] = [58, 65.81793068]

The above coordinates of shall form different polygons which will represent the zone of faults. The following table shall describe the polygons and their respective zones.

Sl.N	Zones of fault		Polygons
1	PD	Partial Discharge	LOP
2	D 1	Discharge of low	BDCA
3	D 2	Discharge of High	DEGFC
4	T 1	Thermal Fault <300 °C	OPQRK
5	T 2	Thermal fault 300 - 700	QNJR
6	T 3	Thermal fault > 700 °C	IJNMH
7	DT	Electrical and Thermal	KRJIHFGED

V. STEPS TO IMPLEMENT IN MATLAB

The MATLAB implementation consists of flow charts and MATLAB programming. Following Steps are used to create a MATLAB program implementing the Duval Triangle Method:

Step-1: Get concentration (in percent) of Acetylene (C_2H_2) , Methane (CH_4) and Ethylene (C_2H_4) .

Step-2: Find the fault locater point (m, n).

Step-3: Patch all the coordinates (A, B, R) to form all Zones of fault.

Step-5: Scatter Fault locating Point (m, n) inside the triangle.

VI. MATLAB CODE FOR DUVAL TRIANGLE

```
function Duval
clc
clear
whos
```

```
% ---------------------------------------------

% ---------------------------------------------
% ---------------------------------------------
h_TRG = figure;                         % Handle Figure
set(h_TRG, 'Name', 'Duval Triangle: Vibhor Kumar Singh')
%set(h_TRG, 'Name', 'Duval Triangle')
set(h_TRG, 'NumberTitle', 'off')
set(h_TRG, 'ToolBar', 'none')                    % Mask ToolBar
set(h_TRG, 'MenuBar', 'none')                    % Mask Menu
set(gcf, 'Color', 'w')
set(gcf, 'Color', [.8 .8 .8])
set(gca, 'visible', 'off')
hold on


prompt = {'Enter concentration of C2H2 in PPM','Enter concentration of CH4 in PPM','Enter concentration of C2H4 in PPM',};
dlgtitle = 'Input:concentration of Gases ';
fieldsize = [1 45; 1 45;1 45];
answer = inputdlg(prompt,dlgtitle,fieldsize);
A_PPM=str2num(answer{1});
B_PPM=str2num(answer{2});
C_PPM =str2num(answer{3});
a=(A_PPM/(A_PPM+B_PPM+C_PPM))*100;
b=(B_PPM/(A_PPM+B_PPM+C_PPM))*100;
c=(C_PPM/(A_PPM+B_PPM+C_PPM))*100;
%a=1;
%b=1;
%c=1;
%---------------------------------------------
abc = [a b c]';
n = b.*sin(pi/3);
m=(100-a)-(b*cos(pi/3));
%---------------------------------------------
x=[0 43.5 23 55.00 63.5 71 55.5 85 67.5 73 48 50 100 75 49 51 60 58];
y=[0 75.34421013 0 55.42562584 40.70319398 0 26.84678752 0 30.31088913 39.83716857 83.13843876 86.60254038 0 43.30127019 84.87048957 84.87048957 69.2820323 65.81793069];
A=[x(1),y(1)];
B=[x(2),y(2)];
C=[x(3),y(3)];
D=[x(4),y(4)];
E=[x(5),y(5)];
F=[x(6),y(6)];
G=[x(7),y(7)];
H=[x(8),y(8)];
I=[x(9),y(9)];
J=[x(10),y(10)];
K=[x(11),y(11)];
L=[x(12),y(12)];
M=[x(13),y(13)];
N=[x(14),y(14)];
O=[x(15),y(15)];
P=[x(16),y(16)];
Q=[x(17),y(17)];
R=[x(18),y(18)];

%region patching
D1=patch([x(1) x(2) x(4) x(3)],[y(1) y(2) y(4) y(3)],'y');
D2=patch([x(3) x(4) x(5) x(7) x(6)],[y(3) y(4) y(5) y(7) y(6)],'r');
DT=patch([x(2) x(4) x(5) x(7) x(6) x(8) x(9) x(10) x(18) x(11)],[y(2) y(4) y(5) y(7) y(6) y(8) y(9) y(10) y(18) y(11)],'g');
T3=patch([x(9) x(10) x(14) x(13) x(8)],[y(9) y(10) y(14) y(13) y(8)],'b');
T2=patch([x(18) x(10) x(14) x(17)],[y(18) y(10) y(14) y(17)],'m');
T1=patch([x(11) x(18) x(17) x(16) x(15)],[[y(11) y(18) y(17) y(16) y(15)]],'c');
PD=patch([x(15) x(12) x(16)],[y(15) y(12) y(16)],'k');

%Parallel Lines
Pa=patch([m (b*cos(pi/3))],[n (b*sin(pi/3))],'b','LineStyle',':','LineWidth',1);
Pb=patch([m (100-a)],[n 0],'b','LineStyle',':','LineWidth',1);
Pc=patch([m (100*cos(pi/3)+c*sin(pi/6))],[n (100*sin(pi/3)-c*cos(pi/6))],'b','LineStyle',':','LineWidth',1);


%marking nodes
text(x(1),y(1),' A','VerticalAlignment','top','FontSize',7);
text(x(2),y(2),' B','FontWeight','bold','FontSize',7);
text(x(3),y(3),' C','VerticalAlignment','top','FontSize',7);
text(x(4),y(4),' D','FontWeight','bold','FontSize',7);
```

```
text(x(5),y(5),' E','FontWeight','bold','FontSize',7);
text(x(6),y(6),'
F','VerticalAlignment','top','FontWeight','bold','FontS
ize',7),
text(x(7),y(7),' G','FontWeight','bold','FontSize',7);
text(x(8),y(8),'
H','VerticalAlignment','top','FontWeight','bold','FontS
ize',7);
text(x(9),y(9),'
I','FontSmoothing','on','FontWeight','bold','FontSize',
7);
text(x(10),y(10),' J','FontWeight','bold','FontSize',7);
text(x(11),y(11),'
K','Rotation',310,'VerticalAlignment','top','Horizontal
Alignment','right','FontSize',7,'FontSmoothing','on','F
ontWeight','bold');
text(x(12),y(12),'
L','VerticalAlignment','bottom','HorizontalAlignment'
,'center','FontWeight','bold','FontSize',7);
text(x(13),y(13),'
M','VerticalAlignment','top','FontWeight','bold','Font
Size',7);
text(x(14),y(14),' N','FontWeight','bold','FontSize',7);
text(x(15),y(15),'
O','Rotation',20,'HorizontalAlignment','right','Vertical
Alignment','bottom','FontSize',7,'FontSmoothing','on',
'FontWeight','bold');
text(x(16),y(16),'                    P','Rotation',-
10,'HorizontalAlignment','left','VerticalAlignment','ba
seline','FontWeight','bold','FontSize',7);
text(x(17),y(17),' Q','FontWeight','bold','FontSize',7);
text(x(18),y(18),' R','FontWeight','bold','FontSize',7);

%Zone naming
text(45,26,'D2');
text(62,26,'DT');
text(77,26,'T3');
text(64,56,'T2');
text(54,74,'T1');
text(27,35,'D1');

%Label Gases
la = ('%C_2H_2=[a]= ');
lb = ('%CH_4=[b]= ');
lc = ('%C_2H_4=[c]= ');

Ta = text(50,0, sprintf('%s%.2f',la,a));
set(Ta, 'VerticalAlignment', 'top','Position',[50,-5]);

Tb = text(20,45, sprintf('%s%.2f',lb,b));
set(Tb,              'HorizontalAlignment',
'left','Rotation',60,'Position',[20,45]);

Tc = text(80, 45, sprintf('%s%.2f',lc,c));
set(Tc,    'HorizontalAlignment',    'right','Rotation',-
60,'Position',[80,45]);

% ----------------------------------------------
% Markings' on sides
% ----------------------------------------------
%for b=CH4
   b_x=(0:50/10:50);
   b_y=(0:86.6025/10:86.60250);
   plot(b_x,b_y,'-ok','LineWidth',1,...
   'MarkerSize',2,...
   'MarkerEdgeColor','k',...
   'MarkerFaceColor','k');



   for j=1:10
   x=b_x(j);
   y=b_y(j);
   s=(j-1)*10;
   text(x,y,sprintf('                         %d
',s),'HorizontalAlignment','left','FontSize',6,'FontWei
ght','bold');

   end
   %for c=C2H4
   c_x=(50:5:100);
   c_y=(86.60250:- 86.6025/10:0);
   plot(c_x,c_y,'-ok','LineWidth',1,...
   'MarkerSize',2,...
   'MarkerEdgeColor','k',...
   'MarkerFaceColor','k');
   for j=1:10
   x1=c_x(j);
   y1=c_y(j);
   s1=(j-1)*10;
   text(x1,y1,sprintf('                       %d
',s1),'HorizontalAlignment','right','FontSize',6,'Rotati
on',30,'FontWeight','bold');
   end

   %for a=C2H2
    a_x=(0:10:90);
 b_y=zeros(1,10);
```

```
    plot(a_x,b_y,'-ok','LineWidth',1,...
    'MarkerSize',2,...
    'MarkerEdgeColor','k',...
    'MarkerFaceColor','k');
     for j=2:10,
    x2=a_x(j);
    y2=b_y(j);
    s2=(11-j)*10;
    text(x2,y2,sprintf('
%d',s2),'VerticalAlignment','bottom','FontSize',6,'FontWeight','bold');

    end

scatter(m,n,30,'k','filled');

end
```

VII. RESULT AND DISCUSSIONS

The programing is executed by taking sample data as Concentration of C_2H_2 (in PPM) = 45 PPM, Concentration of CH_4 (in PPM) = 35 PPM, Concentration of C_2H_4 (in PPM) = 95 PPM. Running the program will prompt a window as given in following figure:

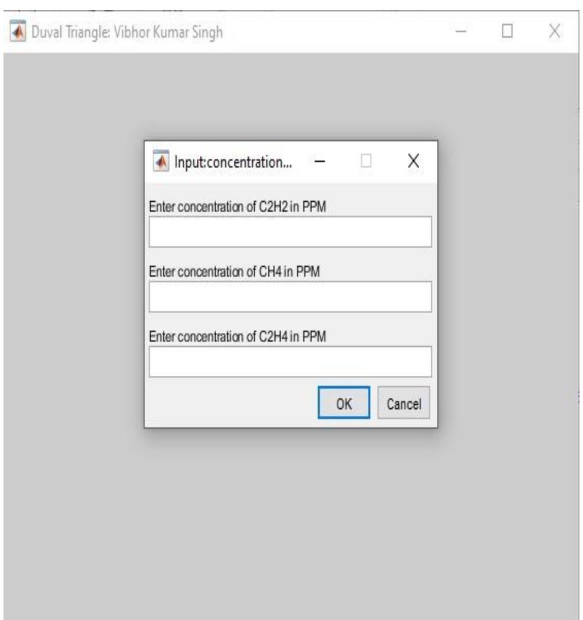

Figure-3: Prompt Window

The result will show fault locating point in DT zone. DT zone suggests for Combination of Electrical and Thermal fault with Low energy discharge.

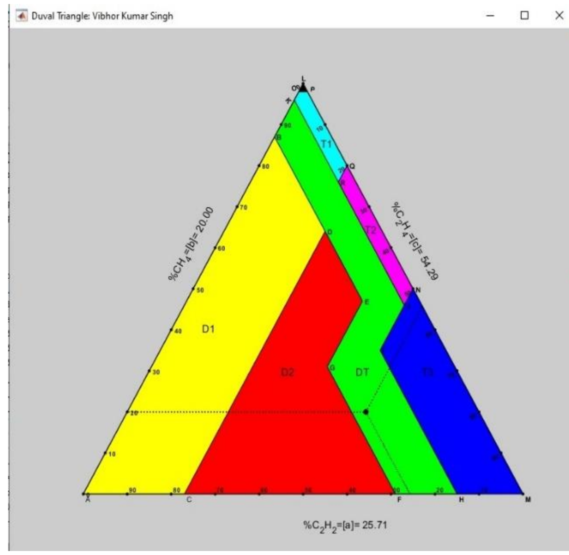

Figure 3: Result window of Duval Triangle

The MATLAB Program for Duval Triangle Method has been prepared and executed correctly. The Location of Zone is correctly represented by use of MATLAB tool.

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