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Case Study on Power Transformer using Dissolved Gas Analysis Technique

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***Abstract*— This paper discusses Dissolved Gas Analysis (DGA) in transformer oil from two 69/24 kV 24/32 MVA installed in urban areas. By detecting unusual increasing gas, then transformer oil samples were collected frequently according to Standards. First transformer was failed by inside short circuit. All loads were transfer to second transformer. The risk of failure on last transformer is very high. Standards used for DGA interpretation is IEEE C57.104. Evaluation of fault type used Key gas method, Doernenburg ratio, Rogers ratio and Duval Triangle.**

Keywords—transformer, Dissolved Gas Analysis, Duval triangle, key gas method

I. Introduction

Power transformer is one of the most importance equipment in electrical network. The health of a power transformer depends on the condition of its major components. Dissolved gas analysis (DGA) is one of the transformer assessment technique to determine the condition of transformer. It can detect certain gases generated in an oil-filled transformer in service. The two principal causes of gas formation within an operating transformer are cellulosic decomposition and oil decomposition [1,6]. The thermal decomposition of oil-impregnated cellulose insulation produces carbon oxides(CO,CO_2) and some hydrogen or methane. Transformer oil contains a mixture of many different hydrocarbon molecules. The decomposition process of these hydrocarbons caused by thermal or electrical faults are highly complex. Gas generation in transformer oil is shown in Fig.1 [1,5].

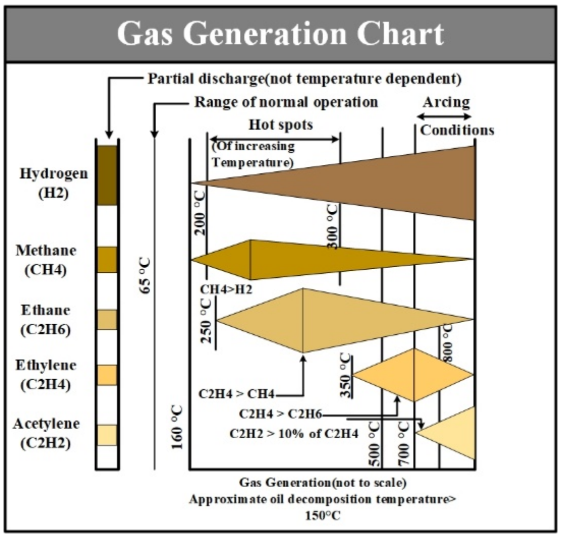

Fig. 1. Gas generation chart.

II. Dissolved Gas Diagnostic Method

The DGA analysis is an important method widely used to monitor transformers in service. The Gas chromatography has been used for DGA analysis. Chromatography is a set of laboratory techniques for separating mixture of gases. There are two main methods to find out abnormal situation within transformer using DGA. The first method uses the absolute value of the gas. The other method uses the gas ratio.

Evaluation using individual and TDCG concentration

A four-level criterion has been developed to classify risk of transformers[2]. The criterion concentration for separate gases and the total concentration of all combustible gases are shown in Table I.

TABLE I. Gas concentration

	Status			
	Condition 1	***Condition 2***	***Condition 3***	***Condition 4***
Hydrogen(H_2)	100	101-700	701-1800	>1800
Methane(CH_4)	120	121-400	401-1000	>1000
Acetylene(C_2H_2)	1	2-9	10-35	>35
Ethylene(C_2H_4)	50	51-100	101-200	>200
Ethane(C_2H_6)	65	66-100	101-150	>150
Carbon Monoxide(CO)	350	351-570	571-1400	>1400
Carbon Dioxide(CO_2)	2500	2500-4000	4001-10k	>10k
TDCG	720	721-1920	1921-4630	>4630

Key Gas Method

According to the guidance of the IEEE C57.104-2008 standard, this method is used when the transformer has no previous dissolved gas history. TDCG is still primarily considered in conjunction with the apparent increase in some gases to identify potential problems of transformers [2]. Fault types identify by this method are shown in Table II.

TABLE II. Fault types by key gas evaluation

Fault type	**Key gas**
Thermal-Oil	C_2H_4
Thermal-Cellulose	CO
Electrical-Partial discharge	H_2
Electrical-Arcing	C_2H_2

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Doernenburg ratios method

This method utilizes four gas ratios R1(CH_4/H_2), R2(C_2H_2/C_2H_4), R3(C_2H_2/CH_4) and R4(C_2H_6/C_2H_2) to identify the fault characteristics of the transformers. The transformer is considered to be anomaly if at least one of the gas concentrations for H_2, CH_4, C_2H_4 and C_2H_2 exceeds twice the values for limit L1 and one of the other two gases exceeds the values for limit L1 as given in Table III. Then the four ratios, R1, R2, R3 and R4, are compared to the limiting values given in Table IV [3,4]. If all gas ratios fall within the values in a row of table IV, then the faults are specified in the first column of Table IV. The suggested diagnosis is valid.

TABLE III. LIMIT CONCENTRATION OF DISSOLVED GAS

Key gas	Limit(ppm)	
	L1	*2L1*
Hydrogen(H2)	100	200
Methane(CH4)	120	240
Carbon monoxide(CO)	350	700
Acetylene(C2H2)	1	2
Ethylene(C2H4)	50	100
Ethane(C2H6)	65	130

TABLE IV. FAULT DIAGNOSIS BY DOERNENBURG RATIO METHOD

Fault type	R1	R2	R3	R4
Thermal decomposition	>1.0	<0.75	<0.3	>0.4
Corona	<0.1	Insignificant	<0.3	>0.4
Arcing	>0.1& <1.0	>0.75	>0.3	<0.4

Rogers Ratios Method

This method considers two of the four ratios introduced by Doernenburg, CH_4/H_2, C_2H_2/C_2H_4, and in addition considers a new ratio, C_2H_4/C_2H_6. This method is effective because it is consistent with the results of many faults by dissolved gas analysis in the transformer oil for each case. However, some aspect ratios do not correspond to the diagnostic code assigned to the various faults in this method. Rogers ratio method has gained popularity in maintenance practices. However, it may give no conclusion in some cases. This method uses three gas ratios to indicate five different types of faults as shown in Table V [3,4].

TABLE V. GAS RATIO CODE FOR ROGER'S RATIO METHOD

Case	R_2	R_1	R_5	Suggested fault
0	<0.1	>0.1 to 1.0	<0.3	Unit normal
1	<0.1	<1.0	1.0 to 3.0	Partial discharge
2	0.1 to 3.0	0.1 to 1.0	>0.3	Arcing
3	<0.1	>0.1 to <1.0	1.0 to 3.0	Low temp. thermal
4	<0.1	>1.0	1.0 to 3.0	Thermal<700 °C
5	<0.1	>1.0	>3.0	Thermal>700 °C

Duval's Triangle

This method is presented by M. Duval using a triangle as shown in Fig.2 to describe the characteristics of the transformer. It is divided into seven fault codes as shown in Table VI [5,6]. The Duval's Triangle method is determined by the percentage of three gases: CH_4, C_2H_2 and C_2H_4 to find the intersection of a straight line within the triangle which indicates the codes of the transformer faults.

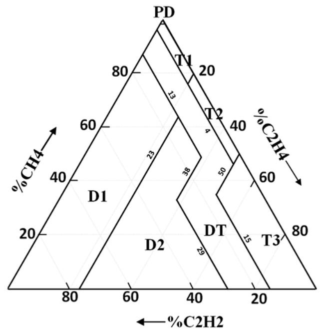

Fig. 2. Duval's triangle.

TABLE VI. FAULT CLASSIFICATION BY DUVAL'S TRIANGLE

Fault code	*Fault type*
PD	Partial discharge
D1	Low energy discharge
D2	High energy discharge
DT	Mixture of electrical and thermal faults
T1	Thermal fault, T<300 °C
T2	Thermal fault, 300<T<700 °C
T3	Thermal fault, T>700 °C

III. DGA DATA FROM TRANSFORMERS

Transformer No.1

The DGA data from both transformers are interpreted using absolute value of gas and gas ratio method. The DGA data used in this paper are sampling three times, 8 September 2015, 22 October 2019 and 30 October 2019.Transformer No.1 ratings are as follows; 24/32 MVA, 69/24 kV, 3-phase, Oil Natural Air Forced(ONAF). It was manufactured by AEG in 1992. The DGA test results of this transformer are shown in Table VII.

TABLE VII. DGA DATA OF THE TRANSFORMER NO.1

Component Gas	Dissolved Gas Concentration(ppm)		
	8-Sep-15	*22-Oct-19*	*30-Oct-19*
Hydrogen(H2)	6	13334	13842
Methane(CH_4)	8	2398	2447
Acetylene(C_2H_2)	0	13	13
Ethylene(C_2H_4)	11	9	10
Ethane(C_2H_6)	1	652	680
Carbon Monoxide(CO)	636	183	191
Carbon Dioxide(CO_2)	4826	1476	1478
TDCG	662	16589	17183

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Transformer No.2

This transformer has the same ratings as transformer no.1 and operated in parallel. The DGA test results of this transformer are shown in Table VIII.

TABLE VIII. DGA DATA OF THE TRANSFORMER NO.2

Component Gas	Dissolved Gas Concentration(ppm)		
	8-Sep-15	*22-Oct-19*	*30-Oct-19*
Hydrogen(H_2)	0	22353	25015
Methane(CH_4)	67	2392	2790
Acetylene(C_2H_2)	0	10	12
Ethylene(C_2H_4)	13	18	21
Ethane(C_2H_6)	28	565	690
Carbon Monoxide(CO)	437	236	251
Carbon Dioxide(CO_2)	2924	1354	1526
TDCG	545	25573	28778

On 1st December 2019, Transformer no.1 failed. The building manager has therefore relocated all electricity load of transformer no.1 to transformer no.2. The DGA result of transformer no.2 also exceeded the standard.

IV. INTERPRETATION OF THE DGA RESULTS

Transformer No.1

The DGA sample of transformer no.1 are given in Table VII. They are interpreted using methods as follows.

A. Evaluation using individual and TDCG concentration

From DGA data on Table VII, The highest gases are H_2, CH_4, C_2H_2, C_2H_6 and TDCG. According to the information, transformer no.1 would be classified as Condition 4 [8,9]. The two gases, Acetylene and Hydrogen, indicate that this transformer is in severe condition and immediate attention is required.

B. Evaluation using key gas method

The percentage of TDCG (%TDCG) are calculated and shown as a graph in Fig. 3. The results shown high amounts of H_2 and CH_4 caused by partial discharge [7]. The gases were likely to increase. Therefore, this transformer must be inspected continuously and maintained.

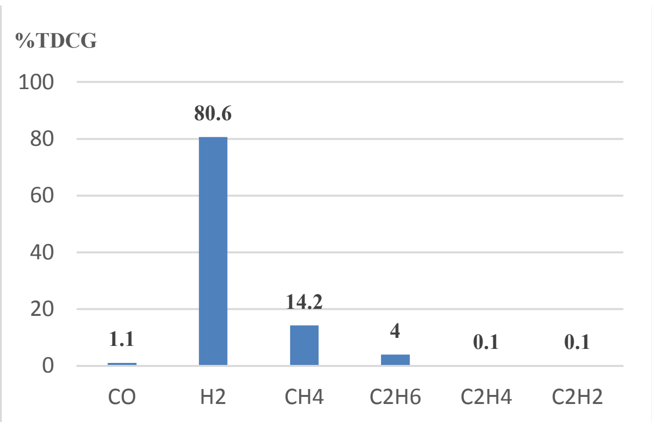

Fig. 3. Key gas result of transformer 1.

C. Evaluation using Doernenburg ratios

The results from the Doernenburg ratio in Table IX shows that PD occurs.

TABLE IX. DOERNENBURG RATIO OF TRANSFORMER 1

Gas Ratio		Suggested fault diagnosis
R1=CH4/H2	0.05	Partial Discharge
R2=C_2H_2/C_2H_4	1.3	
R3=C_2H_2/CH_4	0.02	
R4=C_2H_6/C_2H_2	52.3	

D. Evaluation using Rogers ratio

The results from Rogers ratio in Table X shows fault cannot identify.

TABLE X. ROGERS RATIO OF TRANSFORMER 1

Gas Ratio		Suggested fault diagnosis
R1=CH4/H2	0.05	Fault not identify
R2=C_2H_2/C_2H_4	1.3	
R5=C_2H_4/C_2H_6	0.01	

E. Evaluation using Duval's triangle

Duval triangle result in Fig.4 shows that transformer no.1 falls to PD category.

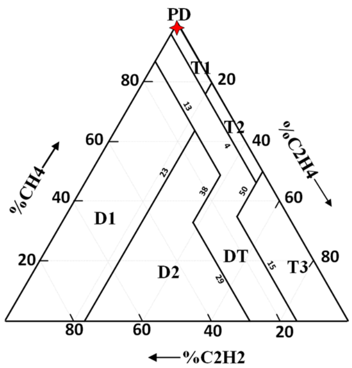

Fig. 4. Duval's triangle result of transformer 1.

Transformer No.2

The DGA sample of transformer no.2 are given in Table VIII. They are interpreted using methods as follows.

A. Evaluation using individual and TDCG concentration

From DGA data on Table VIII, The highest gases are H_2, CH_4, C_2H_2, C_2H_6 and TDCG. According to the information, transformer no.1 would be classified as Condition 4 [8,9]. The two gases, Acetylene and Hydrogen, indicate that this transformer is in severe condition and immediate attention is required.

B. Evaluation using key gas method

The percentage of TDCG (%TDCG) are calculated and shown as a graph in Fig. 5. The results shown high amounts of H_2 and CH_4 caused by partial discharge [7]. The gases were likely to increase. These results are the same as transformer no.1. Therefore, this transformer must be inspected continuously and maintained.

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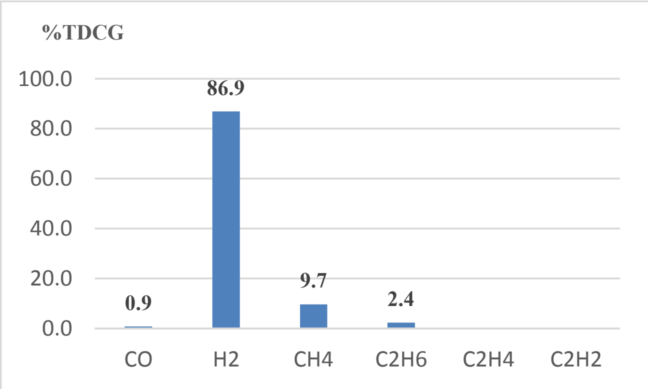

Fig. 5. Key gas result of transformer 2.

C. Evaluation using Doernenburg ratios

The results from the Doernenburg ratio in Table XI show that PD occurs.

TABLE XI. DOERNENBURG RATIO OF TRANSFORMER 2

Gas Ratio		Suggested fault diagnosis
R1=CH4/H2	0.11	Partial Discharge
R2=C_2H_2/C_2H_4	0.57	
R3=C_2H_2/CH_4	0.02	
R4=C_2H_6/C_2H_2	52.3	

D. Evaluation using Rogers ratios

The results from Rogers ratio in Table XII shows fault cannot identify.

TABLE XII. ROGERS RATIO OF TRANSFORMER 2

Gas Ratio		Suggested fault diagnosis
R1=CH4/H2	0.11	Fault not identify
R2=C_2H_2/C_2H_4	0.57	
R5=C_2H_4/C_2H_6	0.03	

E. Evaluation using Duval's triangle

From the total amount of 3 types of gas, it contains 99% of CH_4 and 1% of C_2H_2. Duval triangle result in Fig.6 shows that transformer no.2 falls into PD category.

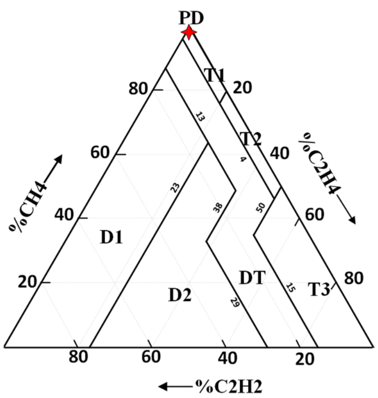

Fig. 6. Duval's triangle result of transformer 2.

V. CONCLUSION

The DGA results from two transformers in service are reported and its interpretation is given with reference to prevailing standard. The DGA results used four analytical methods. The results are summarized that both transformers should be replaced immediately and the results shows a very high risk of failure.. However, since the building was unable to immediately turn off the electricity supply, the transformer oil samples were frequently collected. In this case study, the individual and TDCG concentration and key gas method are sufficient to indicate the fault in transformers. The engineering judgement can be applied to determine the final sampling interval and operating procedure. In this case , It should be consider removal from service immediately.

The results from ratio methods are similar for both transformers. The analysis results from the Doernenburg ratio and the Duval triangle showed that partial discharge occurred. The three gas ratio methods(Doernenburg ratio, Rogers ratio and Duval's triangle) can't provide complete diagnosis for the fault present in these transformers.

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REFERENCES

[1] Jeff Golarz,"Understanding Dissolved Gas Analysis (DGA) Techniques and Interpretations," 2016 IEEE/PES Transmission and Distribution Conference and Exposition (T&D), pp.1-5, 2016.

[2] "IEEE Guide for the interpretation of Gases Generated in Oil-Immersed Transformers," IEEE Std.C57.104- 2008, 2008.

[3] W. Wattakapaiboon, N. Pattanadech,"The State of The Art for Dissolved Gas Analysis Based on Interpretation Techniques," 2016 International Conference on Condition Monitoring and Diagnosis, pp.60-63, 2016.

[4] T.Bhavani Shanker,H.N.Nagamani,Deepthi Antony,and Gururaj S Punekar,"Case Studies on Transformer Fault Diagnosis using Dissolved Gas Analysis," 2017 IEEE PES Asia-Pacific Power and Energy Engineering Conference(APPEEC), pp.1-3, 2017.

[5] Ekkarach Wannapring, Cattareeya Suwanasri, Thanapong Suwanasri,"Dissolved Gas Analysis Methods for Distribution Transformers," 13th International Conference on Electrical Engineering/Electronics,Computer,Telecommunications and Information Technology(ECTI-CON), pp.1-6, 2016.

[6] N. Pattanadech, and W. Wattakapaiboon,"Application of Duval Pentagon Compared with Other DGA Interpretation Techniques: Case Studies for Actual Transformer Inspections Including Experience from Power Plants in Thailand," 2019 5th International Conference on Engineering,Applied Sciences and Technology(ICEAST), pp.1-4, 2019.

[7] Triparna Nandy, Amit Gupta, Nikhileshwar P. Adhikari, "Study of Dissolved Gas Analysis for Pre Determination of Faults in Transformers," 2016 International Conference on Computation of Power, Energy Information and Commuincation (ICCPEIC), pp.634-642, 2016.

[8] S. N. Hettiwatte, H. A. Fonseka,"Analysis and interpretation of dissolved gases in transformer oil: A case study," 2012 IEEE International Conference on Condition Monitoring and Diagnosis, pp.35-38, 2012.

[9] N.A. Muhamad, B.T. Phung, T.R. Blackburn, K.X Lai,"Comparative Study and Analysis of DGA Methods for Transformer Mineral Oil," 2007 IEEE Lausanne Power Tech,pp.45-50, 2007.

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