Journal of the Korean Institute of Illuminating and Electrical Installation Engineers Vol. 21, No.9, pp. 87~94 November 2007 (21-9-13)

The New Criteria of Dissolved Gas Analysis for Oil-Filled Transformers Using a Cumulative Distribution Function

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Abstract

This paper presents new criteria for DGA (Dissolved Gases Analysis) using CDF (Cumulative Distribution Function) obtained from the data from the diagnosis of transformers operated in KEPCO over a period of 16 years. Because of differences in operating environments, construction type, oil volume, and other factors, the interpretative criteria of DGA at KEPCO differs from other standards such as IEC-60599, or Rogers and Doernenburg. To suggest the most appropriate criteria, the DGA data from transformers under normal conditions as well as from developing fault transformers were collected. Using these data, this study suggests the limitative gas level of transformers under normal operating conditions and verifies the suitability of the criteria. Because the application of this new criterion to transformers at KEPCO increases the detectable ratio of incipient faults and reduces unnecessary follow-up sampling and analysis, the new criteria yields a more reliable prediction of transformer condition.

Key Words : Transformer, Dissolved Gas Analysis, Diagnosis

1. Introduction

Power transformers are essential for a transmission and distribution system. Faults in power transformers may cause a breakdown in power supply and loss of profit. Therefore, in order to repair power transformers safely and to improve the reliability of power systems, it is very important to detect incipient fault as early as possible.

Because of the importance of power transformers, there are many diagnostic techniques for the earlier detection of developing faults. The dissolved gases analysis (DGA) is one of the most useful techniques to detect incipient faults in power transformers. It periodically samples the insulation oil of transformers to obtain the constituent gases in the oil which are formed due to the overheating and discharge of the insulating materials inside. As a result of DGA, a quantity of gases can be obtained: hydrogen (H_2), acetylene

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Date of submit : 2007. 9. 17
First assessment : 2007. 9. 27
Completion of assessment : 2007. 10. 11

(C_2H_2), ethylene (C_2H_4), methane (CH_4), ethane (C_2H_6), carbon monoxide (CO) and others. Considering the concentration of each gas, it can be decided whether the condition of the transformer is safe, or whether it requires maintenance [1].

There are many interpretative methods based on DGA for diagnosing the condition of a transformer, such as the IEC ratio codes, and the Rogers, Doernenburg and Triangle methods, which were developed from investigations of gases formed from actual developing problems [2-3].

Because the generation of gases is related to the features of the transformer such as oil volume, operation environment, construction type, and others, these diagnostic methods, which do not take into consideration the characteristics of the power transformers at KEPCO, are not appropriate.

To increase the accuracy of diagnosis, some utilities publish criteria that consider the characteristics of their own transformers [4-5].

Therefore, a study of an appropriate interpretation method of DGA that takes into consideration the features of the power transformer at KEPCO has been made.

KEPCO has been performing DGA since 1982 and results of these tests have been stored in the Maintenance System.

Results from 37,782 DGA tests along with 122 reports of transformers in which incipient fault were detected have been collected.

2. Analyzing the DGA of KEPCO

2.1 Criteria of DGA at KEPCO

To ensure safe operation of its more than 4,300transformers, KEPCO periodically performs a DGA every year. As a result of DGA, a quantity of TCG and seven gases have been obtained: hydrogen (H_2), acetylene (C_2H_2), ethylene (C_2H_4), methane (CH_4), ethane (C_2H_6), carbon monoxide (CO) and propane (C_3H_8). The TCG (Total Combustible Gases) is the sum of these seven gases.

The condition of the transformers is diagnosed by applying the concentration of these seven gases and TCG to the criteria for interpretation. The DGA criteria of KEPCO classify the condition of each transformer into four steps: normal, caution, abnormal and danger.

Where the concentration of at least one of the seven gases exceeds the range of normal concentration, the result of 'caution' is diagnosed.

For example, if other concentrations of gases are in the normal range and the concentration of acetylene is 30[ppm], the result is that of caution.

If the result of DGA is caution, a follow-up sampling is executed after three month and if the result of the DGA is abnormal, a follow-up sampling is executed after one month. The transformer classified as a danger is investigated as soon as possible.

Because the transformers that are classified as of a normal condition are not assigned follow-up maintenance action, it is important to differentiate between a normal range of gas and a range that requires action.

Table 1 shows the interpretation criteria of DGA[6].

Fig. 1 shows which gas is a frequent cause for cautionary conditions.

Carbon monoxide is the most frequent causative gas in all conditions. Ethane is the second most frequent causative gas.

Table 1. The interpretation criteria of DGA (Unit : ppm)

	Normal		Caution		Abnormal		Danger	
	154[kV]	345[kV]	154[kV]	345[kV]	154[kV]	345[kV]	154[kV]	345[kV]
H_2	~399		400~800		801~1,200		1,200~	
CO	~399	~349	400~700	350~600	701~1000	601~800	1,000~	800~
C_2H_2	~24	~19	25~80	20~60	81~150	61~120	150~	120~
CH_4	~249		250~750		751~1,000		1,000~	
C_2H_4	~299		300~750		751~1,000		1,000~	
C_2H_6	~249		250~750		751~1,000		1,000~	
C_3H_8	~249		250~750		751~1,000		1,000~	
T.C.G	~999		1,000~2,500		2,501~4,000		4,000~	

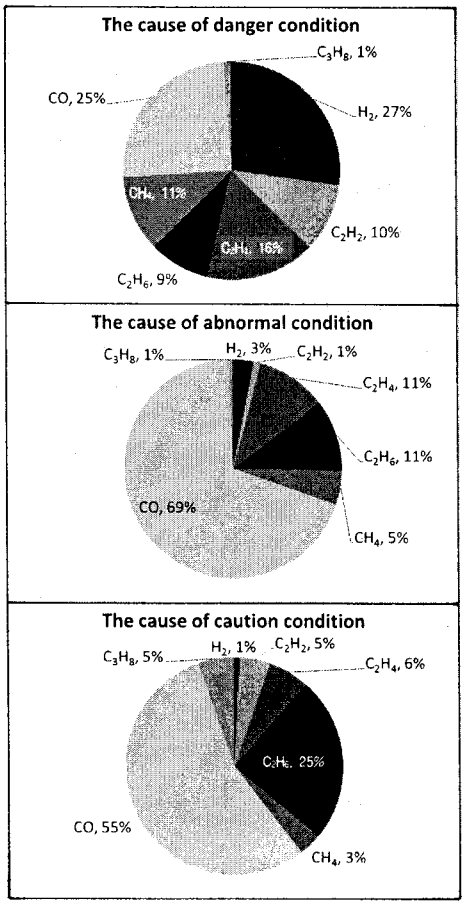


Fig. 1. The percentage of causative gases

2.2 The Results of Inner Inspection

Reports of incipient fault transformers that have been investigated since 2000 have been compiled because of the alarm arising from DGA. The reports of sixty-four inside inspections have been collected.

When an inside inspection of power transformers takes place, an incipient fault is sometimes undetected. When the result of the DGA is constantly that of caution or abnormal conditions, an inside inspection of the power transformers is performed. That the normal range of DGA criteria is inappropriate must be considered.

Fig. 2 shows the ratio of incipient fault detection.

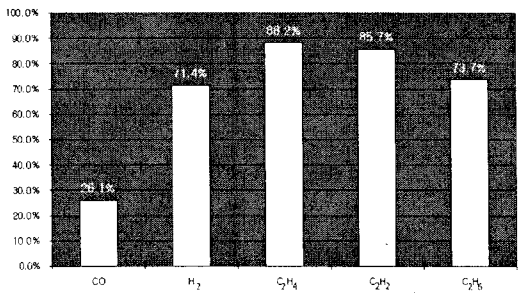


Fig. 2. The percentage of incipient fault detection

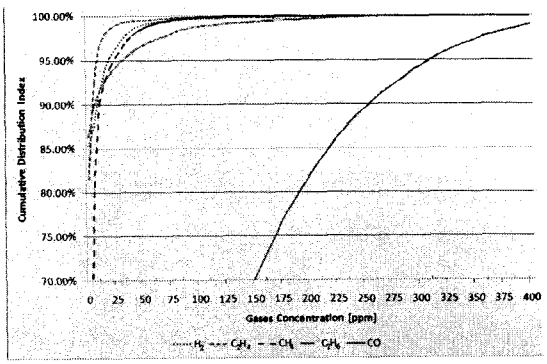
The cause of a low percentage of incipient fault detection for carbon monoxide results from the inappropriateness of the criteria. Because the DGA criteria are inappropriate, carbon monoxide very frequently causes cautionary conditions.

Changing the normal range of the DGA criteria has two meanings. Even though increasing the normal range of the DGA criteria decreases unnecessary follow-up analyses, the probability of finding a developing fault in a transformer is decreased as well. Decreasing the normal range of

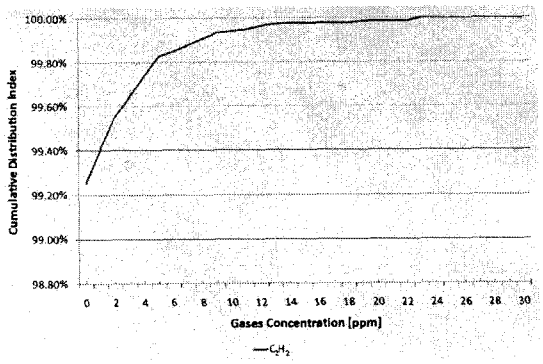
the DGA criteria increases unnecessary follow-up analyses and the probability of finding developing faults. Changing the normal range of DGA criteria, therefore, is not easy.

2.3 Analyzing the Gaseous Concentration of Normal Transformers

The range of the concentration of gases for a normal state was established using the recorded DGA data of normal transformers. In this study, the DGA data from 3,585 normal transformers were collected.



(a) The cumulative distribution function index (CDFI) of H_2, C_2H_4, CH_4, C_2H_6, CO



(b) The cumulative distribution function index (CDFI) of C_2H_2

Fig. 3. The cumulative distribution function curve of normal transformers

The gas levels of transformers under normal conditions were found using a CDF curve plotted with the gathered data.

Fig. 3 shows the CDF curve based on the type of gas.

This paper suggests that the concentration corresponding to 99.9[%] of the CDF be used for the normal concentration value.

Only 0.1[%] of the DGA results from normal transformers exceed the suggested criteria. The suggested range of concentration for transformers in a normal state is shown in Table 2.

Table 2. The suggested concentration ranges of normal transformers (PPM)

	H_2	C_2H_2	C_2H_4	C_2H_6	CH_4	CO
154[kV]	~199	~19	~159	~299	~159	~749
345[kV]		~16				

2.4 Analyzing the Concentration of Gases for Transformers Developing a Fault

To verify that the suggested concentration of gases is correct for detecting incipient faults, the DGA data for transformers developing a problem was collected. Seventy-seven data samples from faulty transformers were collected; due to an insufficiency of data, however, the CDF was plotted (Fig. 5) using Weibull Cumulative Distribution Functions (WCDF).

Equation 1 shows how the WCDF was obtained.

$$F(x) = 1 - e^{-\left(\frac{x}{\eta}\right)^m} \quad (1)$$

Here, x= concentration
m= shape parameter
η = scale parameter

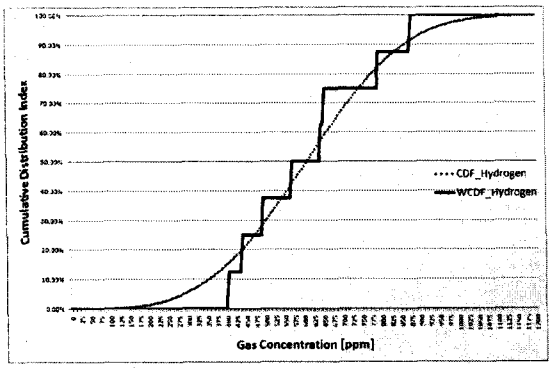
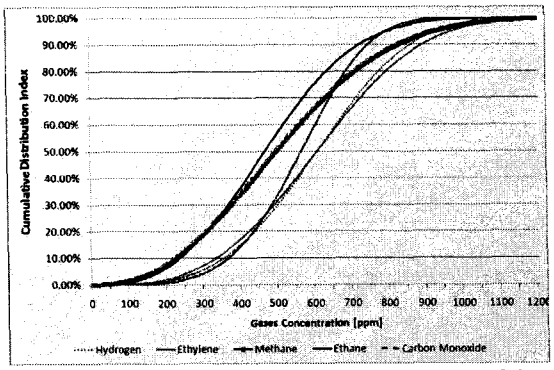
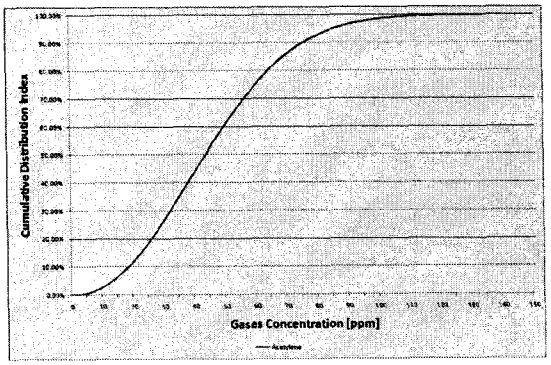


Fig. 4. The comparisons between WCDF and CDF



(a) The WCDF of H_2, C_2H_4, CH_4, C_2H_6, CO



(b) WCDFI of C_2H_2

Fig. 5. The Weibull Cumulative Distribution Function curve for transformers developing a fault

The Weibull Distribution is one of the most widely used lifetime distributions in reliability engineering. It is a versatile distribution that can take on the characteristics of other types of distributions, based on the values of the shape and scale parameters.

The shape and the scale parameters were found using the Weibull sheet method [7].

The WCDF and CDF of H_2 were compared in Fig. 4. Based on a sufficient amount of data, the WCDF and the CDF yield similar results.

Comparing the established criteria with the suggested criteria, the detectable percentage of incipient faults was calculated using WCDF. The detectable percentage of incipient faults for H_2, C_2H_2, C_2H_4 and CH_4 was increased as shown in Table 3.

The detectable percentage of incipient faults for C_2H_6 and CO, however, decreased due to the increasing of the concentration of the criteria.

Table 3. The detectable percentage of incipient faults as a result of changing concentrations for the normal range

	Established Criteria		Suggested Criteria	
	154[kV]	345[kV]	154[kV]	345[kV]
H_2	84.4 [%]		98.5 [%]	
C_2H_2	69.7 [%]	86.3 [%]	87.8 [%]	91.1 [%]
C_2H_4	90.5 [%]		97.9 [%]	
C_2H_6	87.9 [%]		81.6 [%]	
CH_4	81.1 [%]		93.0 [%]	
CO	83.9 [%]		6.0 [%]	

Because the detectable percentage of carbon monoxide decreased remarkably, the increased criterion for carbon monoxide is not correct. The 77[%] decrease for the detectable percentage of carbon monoxide is too great. Hence, another criterion appropriate for carbon monoxide must be found.

3. Verifying the Proposed

Criteria by Application to Recorded DGA Data

To verify that the suggested concentration of gases is usable, the suggested criteria were applied to approximately 37,000 data samples from the power transformers in operation at KEPCO.

First, the four gases H_2, C_2H_2, C_2H_4 and CH_4 were analyzed. The criteria concentrations for these gases were found to have decreased.

The decreasing of the criteria changes the diagnosis of normal conditions to caution conditions. For example, 300[ppm] of hydrogen was diagnosed as a normal condition by the established criteria, but was changed to caution conditions with the suggested criteria.

Table 4. The figure of transformer based on case

		I CASE	II CASE	III CASE	TOTAL
H_2		11	17	7	35
C_2H_2	154[kV]	6	8	3	17
	345[kV]	1	5	2	8
C_2H_4		33	109	18	160
CH_4		5	55	9	69

The 292 samples of changed DGA diagnoses were analyzed. As a result, the data were divided into five cases. First, when the concentration was decreased after the diagnosis of caution in accordance with the established criteria, the data was classified as Case 1. The concentration of data classified as Case 2 increased continuously after the DGA diagnosis. Case 2 refers to incipient faults in power transformers that are able to be detected earlier. Finally, when the concentration increased only once, the data are classified as Case 3. Case 3 most likely occurs due to errors in extracting gas from insulation oil. Case 3 sometimes occurs when the criterion for hydrogen is 400[ppm]. A figure of these Cases was arranged in Table 4 according to type of gas. The high ratio of Case 2 means that a developing fault can be detected earlier. The suggested criteria for these four gases are, therefore, correct.

In the second analysis, the two gases C_2H_6 and CO were analyzed. The criteria for these gases were increased. The change of the figure for caution conditions figure is a result of the change of DGA criterion shown in Fig. 6 and 7.

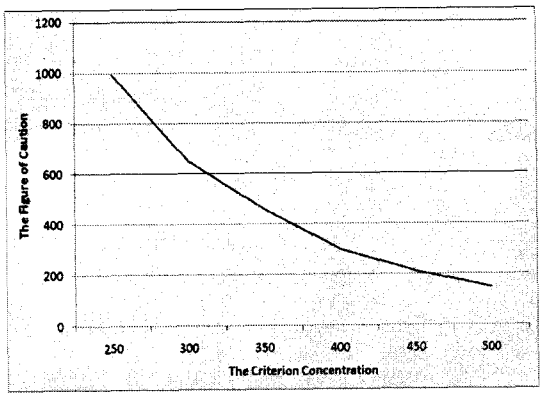


Fig. 6. The figure of caution condition due to ethane concentration

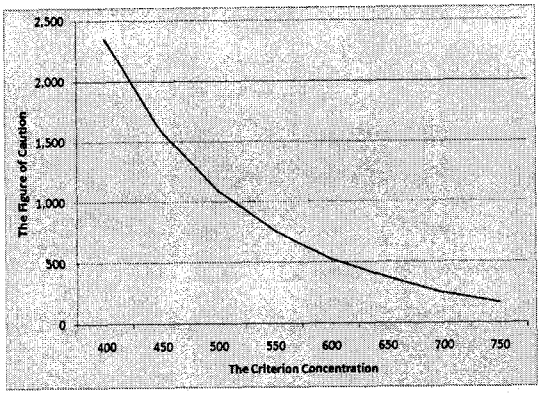


Fig. 7. The figure of caution condition due to carbon monoxide concentration

The criteria suggested in Table 2 cause the decrease of the figure for caution conditions. The criterion for ethane causes 350 reductions in the

figure for caution conditions and a 6.3[%] reduction in the detectable ratio of incipient faults. The criterion of ethane presented in Table 2 is not without fault but it is, however, appropriate. The criterion for carbon monoxide causes 2,300 reductions in the figure for caution conditions and a 77[%] reduction in the detectable ratio of incipient faults. Because extreme reduction of the figure for caution conditions caused by the suggested criterion for carbon monoxide, it is effective. The detectable ratio of developing faults may, however, be reduced too greatly.

Therefore, considering the detectable ratio and the figure of caution conditions, it is suggested that the new criterion for carbon monoxide be 450[ppm].

4. Case Study

The case verifying that the suggested criteria are more appropriate than other criteria in use is shown in Table 5. Only the suggested criteria diagnose this case as a case for caution. Fig. 8 shows the particles of steel detected in the transformer. Because of these particles, electrical discharge occurred.

The suggested concentration range for transformers under normal conditions and other criteria are compared in Table 6.

Table 5. Comparing the suggested concentrations and other criteria (PPM)

Concentration						The result of diagnosis		
H_2	C_2H_2	C_2H_4	C_2H_6	CH_4	CO	IEEE C57.104	IEC 60599	New Criteria
58	29	24	83	63	257	Normal	Normal	Caution

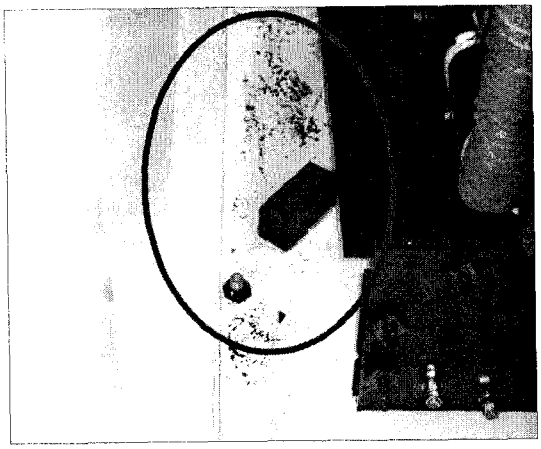


Fig. 8. The detected particle of steel

Table 6. Comparing the suggested concentrations and other criteria (PPM)

	New Criteria		IEEE C57.104	IEC60599
	154[kV]	345[kV]		
H_2	~199		~100	~150
C_2H_2	~19	~16	~35	~50
C_2H_4	~159		~50	~280
C_2H_6	~299		~65	~90
CH_4	~159		~120	~110
CO	~449		~350	~900

5. Conclusion

In this paper, the best criteria for the DGA of transformers at KEPCO were presented. 99.9[%] of the DGA results from normal transformers do not exceed the suggested criteria.

The degree of detection for a developing fault was verified for the criteria. This verification was carried out using the transformer DGA data in which developing faults were detected. It was confirmed that the suggested criteria help to increase the detectable percentage of incipient faults. The appropriateness of criteria was verified using the data of all DGA results obtained at KEPCO. It was also confirmed that the use of the suggested criteria aids in the earlier detection of

faults. Because the criteria for ethane and carbon monoxide are ambiguous, an average is suggested for these concentrations.

In conclusion, the concentration ranges which are proposed in this paper for normal transformers are more appropriate than other criteria of this type.

Acknowledgment

We gratefully acknowledge the support of Korea Electric Power Corporation, for financial support.

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