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Comparison of Dissolved Gas Analysis Interpretation Methods for Power Transformer

Dhiastara Rahmanda* & Suwarno

School of Electrical Engineering and Informatics, Institut Teknologi Bandung, Bandung, Indonesia
*Email: 23221314@std.stei.itb.ac.id

Abstract. In this works, a comparison is made regarding the interpretation of Dissolved Gas Analysis for power transformer using IEEE C57.104-2019, IEEE C57.104-2008, and IEC 60599-2022. The purpose of this work is to know which typical value from those standards that more in line with the actual conditions of the power transformer. The database that is used to make this comparison is 125 DGA data mineral oil from 50 power transformers that are in operation. The DGA database has been confirmed by further testing to find out more about the actual condition of the power transformer. From the comparison results, the interpretation using IEC 60599-2022 has the highest accuracy, followed by IEEE C57.104-2008, then IEEE C57.104-2019. The reason for that result is because in IEEE C57.104-2019 there are typical values that are quite strict, especially on the value of Delta and Gas Rates.

Keywords: *Transformer; Dissolved Gas Analysis; Mineral Oil; IEEE C57.104-2019; IEC 60599-2022.*

1 Introduction

The power transformer is the most expensive asset in the transmission and distribution network [1]. To distribute electricity to other places, the power transformer is one of the most important things [2]. It can increase or decrease the voltage as needed. The important role of the power transformer suggests that we must regularly monitor the condition of the power transformer so that if there is a disturbance or problem with the power transformer, it can be detected earlier before the disturbance that occurs causes more severe problems.

One method for monitoring the condition of the power transformers, especially in oil-immersed transformers is Dissolved Gas Analysis. Dissolved Gas Analysis is a method that is widely used to detect the incipient fault in a power transformer [3]. The method is carried out by looking at the dissolved gas content in the transformer oil [4]. Each gas content produced in transformer oil can be predicting whether the condition of the power transformer is under normal conditions or abnormal conditions. It can also predict the fault type that occurs in the power transformer.

There are several guidelines for interpreting the dissolved gas in transformer oil to distinguish gas content is a normal or abnormal condition. The most commonly used guidelines are IEEE C57.104 and IEC 60599. The New IEEE C57.104 just published in 2019 is the result from revised IEEE C57.104-2008, while the most recent IEC 60599 is IEC 60599-2022. Both standards provide information regarding the normal characteristics of the dissolved gas content in power transformer oil. IEEE C57.104 uses more than 1 million DGA data and IEC 60599 uses 20,000 DGA data which results in the typical value of dissolved gases in the power transformer.

However, in the application of these standards in the interpretation of DGA, there are still some possibilities of false negatives or false positives. From the literature study conducted there has been no research that has made comparisons of these standards in detecting gas abnormalities, most of the comparisons made are comparisons related to the identification of initial disturbances that occur.Therefore, in this study, the accuracy of some of these standards will be compared in detecting gas abnormalities, especially in DGA which has not been in Extreme conditions based on [5].

2 Materials and Methods

2.1 Database description

The DGA database used by the author in this paper is data from the PT Petrolab Service laboratory. The database is the sample oil from an energized power transformer. The gas content in the database is hydrogen, methane, ethane, ethylene, acetylene, oxygen, nitrogen, carbon monoxide, and carbon dioxide with units of parts per million (ppm).

The amount of DGA data used is 125 DGA data from 50 power transformers. The transformers are divided into 40 transformers with a nominal voltage of 20 kV, 2 transformers with a nominal voltage of 70 kV, 3 transformers with a nominal voltage of 150 kV, and 5 transformers with a nominal voltage of 500 kV. The DGA database is the data that has been confirmed by the condition of the power transformer in the field. The confirmations meant are electrical tests, internal inspections, gas monitoring after the transformer oil treatment, for example, purification and oil changes, or confirmation of other tests, such as furan testing, by also looking at the development of the gases produced.

2.2 Description of Anlyzed Criteria

The DGA database that has been collected is interpreted using several interpretation standards, namely, IEC 60599-2022 [6], IEEE C57.104-2008 [7], and IEEE C57.104-2019. After the interpretation is carried out using the three interpretation standards, then the results will be checked by the transformer conditions in the field. In this way, the accuracy or representative level of the typical values of each standard is obtained.

3 Result and Discussion

3.1 Database Analysis

The database consists of the gas content of the oil immersed-transformer mineral oil. The data is divided into two status conditions, normal and abnormal. Normal status is categorized if the information on the condition of the transformer has been obtained from checking by the transformer owner or monitoring of several samples has been carried out after an oil treatment activities such as purification or after being included by other tests, such as furan testing. An abnormal status is given when information on the condition of the transformer is found when an internal inspection or electrical test is carried out, or after monitoring the gas content after the purification process, the gas content continues to increase significantly or from other test confirmations indicating relevance to high gas content, for example, the relevance between gas content of Carbon monoxide and Carbon dioxide with furan content as in the study [8].

Electrical tests, such as Insulation resistance, Turn to Turn Ratio, DC Winding Resistance can confirm the DGA results interpreted using IEE C57.104 or IEC 60599, which indicates an initial fault in the transformer. So if the DGA interpretation results have the same result as the actual condition, the typical value that is used is representative enough, so it can be said that the interpretation is correct. However, if after the electrical test no findings, but the DGA interpretation give the result is abnormal status, it is necessary to monitor again for some DGA sample to determine the condition of the transformer because in some case the incipient fault can't be detected by the electrical test.

Purification of transformer oil can reduce significantly the gas content in transformer oil [9]. If the DGA interpretation result, used IEEE C57.104 or IEC 60599, is abnormal but after purification is carried out and resampling some sample DGA and resulting the gas rates are normal condition it can be concluded the transformer is in normal condition. So, the DGA interpretation doesn't have the same result as the actual condition.

Some data, especially if there is significant CO and CO2 content, is confirmed with furan content and also periodic monitoring after purification to confirm whether the CO2 or CO conditions, that interpreted according to IEC 60599 or IEE C57.104, are correct due to abnormal decomposition of the paper.

3.2 IEEE C57.104-2019

One of the widely used methods for interpreting DGA is IEEE C57.104-2019. The scope of this standard only differentiates power transformers based on their age and ratio of oxygen and nitrogen. wind turbine transformers or network transformers and only for mineral oil in main tanks. It provides clearer interpretation details than IEEE C57.104-2008, one of which is the typical value of the rate of gas development for each gas content. Generally, the flow chart of DGA interpretation using IEEE C57.104-2019 is shown in Figure 1. DGA status using this standard is divided into DGA status 1, DGA Status 2, DGA status 3. So in this work, the normal condition is if DGA interpretation results in DGA status 1. And abnormal conditions if the interpretation results in DGA status 2 or DGA status 3.

Accuracy of DGA status results from Interpretation using IEEE C57.104-2019 with actual transformer conditions can be seen in Table I. There are 32% of DGA status data from 50 transformers that have the same result as the actual condition. The reason for that may be caused by the strict limitations given by IEEE C57.104-2019, especially on the limits of the Gas Rates value and the Delta value at IEEE C57.104-2019 so that a lot of data are categorized as DGA status 2 or DGA status 3 because its value even with low gas content.

The gas rates value is calculated based on the value of the slope (gradient) of 3-6 samples in a period of 2 years, it also often makes the gas rates exceed the limit value in table 4 in IEEE C57.104-2019. Gas rates rule and value in IEEE C57.104-2019 has also been questioned in research [10]. Therefore, it may be necessary to make adjustments to the typical values of Delta and gas rates. It makes DGA interpretation less efficient in determining DGA status.

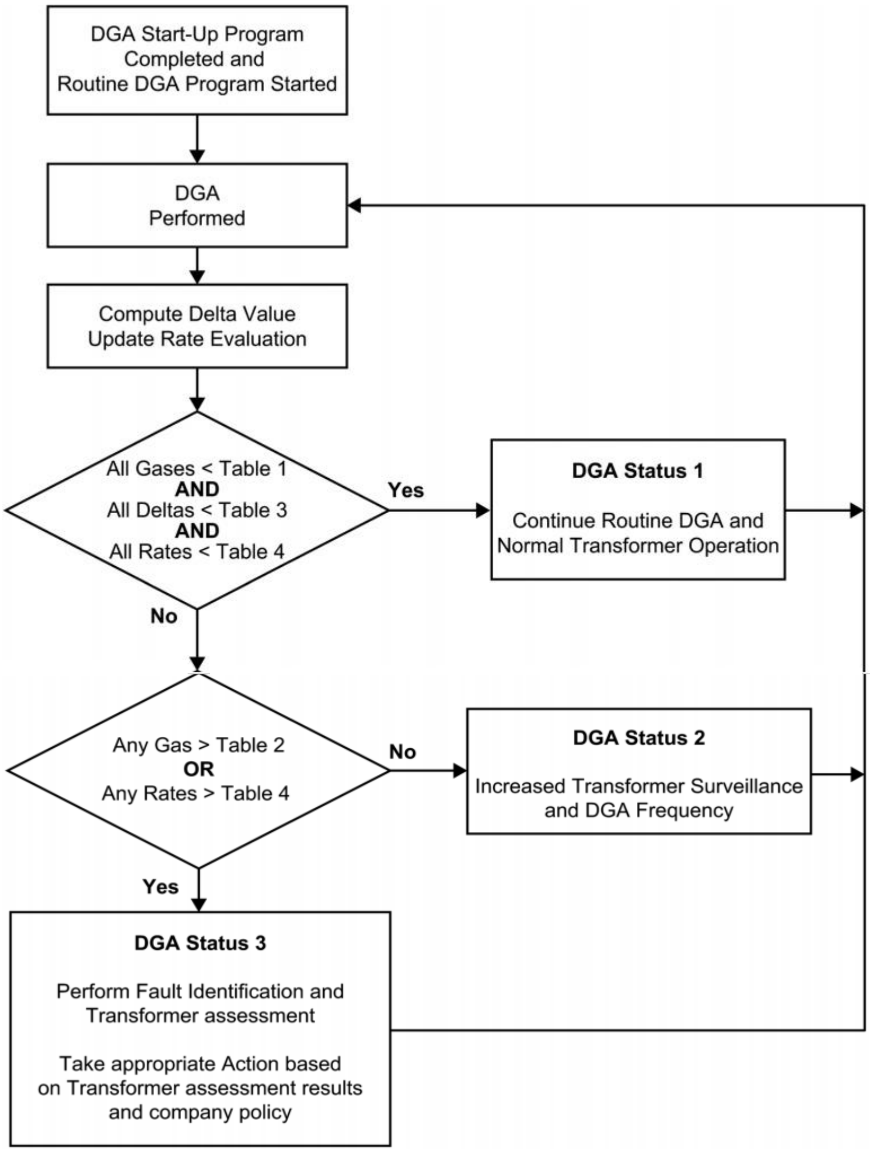

Figure 1 Flow chart IEEE C57.104-2019 Interpretation

3.3 IEEE C57.104-2008

IEEE C57.104-2008 can be applied to power transformers that use mineral oil, but there are notes in this standard, the numbers in this limitation are in parts of gas per million parts of oil [μL/L (ppm)] volumetrically and are based on a large power transformer with several thousand gallons of oil. With a smaller oil volume, the same volume of gas will give a higher gas concentration. Small distribution transformers and voltage regulators may contain combustible gases because of the operation of internal expulsion fuses or load break switches. The status codes in this limitation are also not applicable to other apparatus in which load break switches operate under oil. The accuracy of the DGA interpretation using the typical value of IEEE C57.104-2008 is higher than that of IEEE C57.104-2019. The accuracy is 68% from the actual condition of 50 power transformers as shown in Table I. One of the reasons for this is that the typical value of IEEE C57.104-2008 is not as strict as IEEE C58.104-2019.

Typical values for individual gas content in IEEE C57.104 2008 are divided into 4 conditions for each individual gas, namely H2, CH4, C2H6, C2H4, C2H2, CO, CO2. If there are one or more gases content is outside condition 1, the rate of development of the Total Dissolved Gas Analysis value will be checked. However, if all gases are in condition 1 then the DGA status is normal. This is what makes it different from IEEE C57.104-2019, where the latest IEEE will still give DGA an abnormal status even though the gas content is low, but with Gas rates that exceed the typical value in that standard.

However, this IEEE C57.104-2008 standard lacks in looking at the gas rate of individual gases. For example, if there is acetylene content outside condition 1 and increases significantly (other combustible gas is normal condition), then the DGA interpretation using this standard may not detect this. The flow chart of DGA interpretation using this standard can be seen in Figure 2.

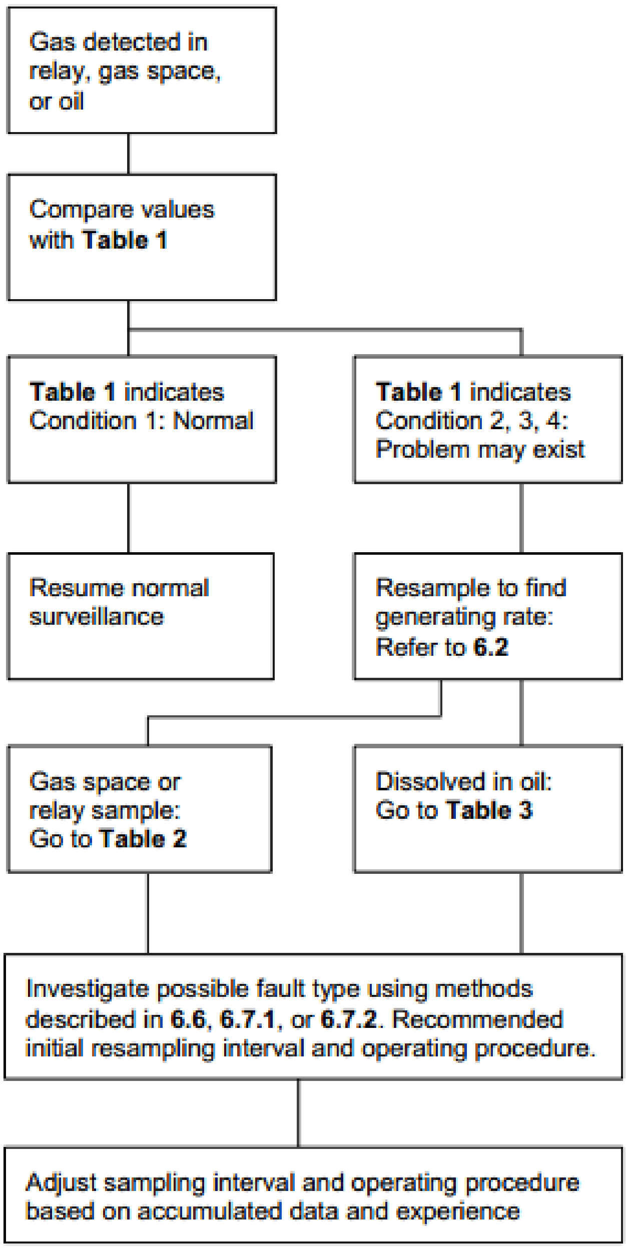

Figure 2 Flow chart IEEE C57.104-2008 Interpretation

3.4 IEC 60599-2022

One of the guidelines for the interpretation of DGA which is also widely used is IEC 60599-2022. Note in this standard is typical values in this standard recommended for large power transformers with an oil volume > 5 000 liters. Values in small transformers (< 5.000 l) are usually lower. The flow of interpretation using this standard can be seen in Figure 3.

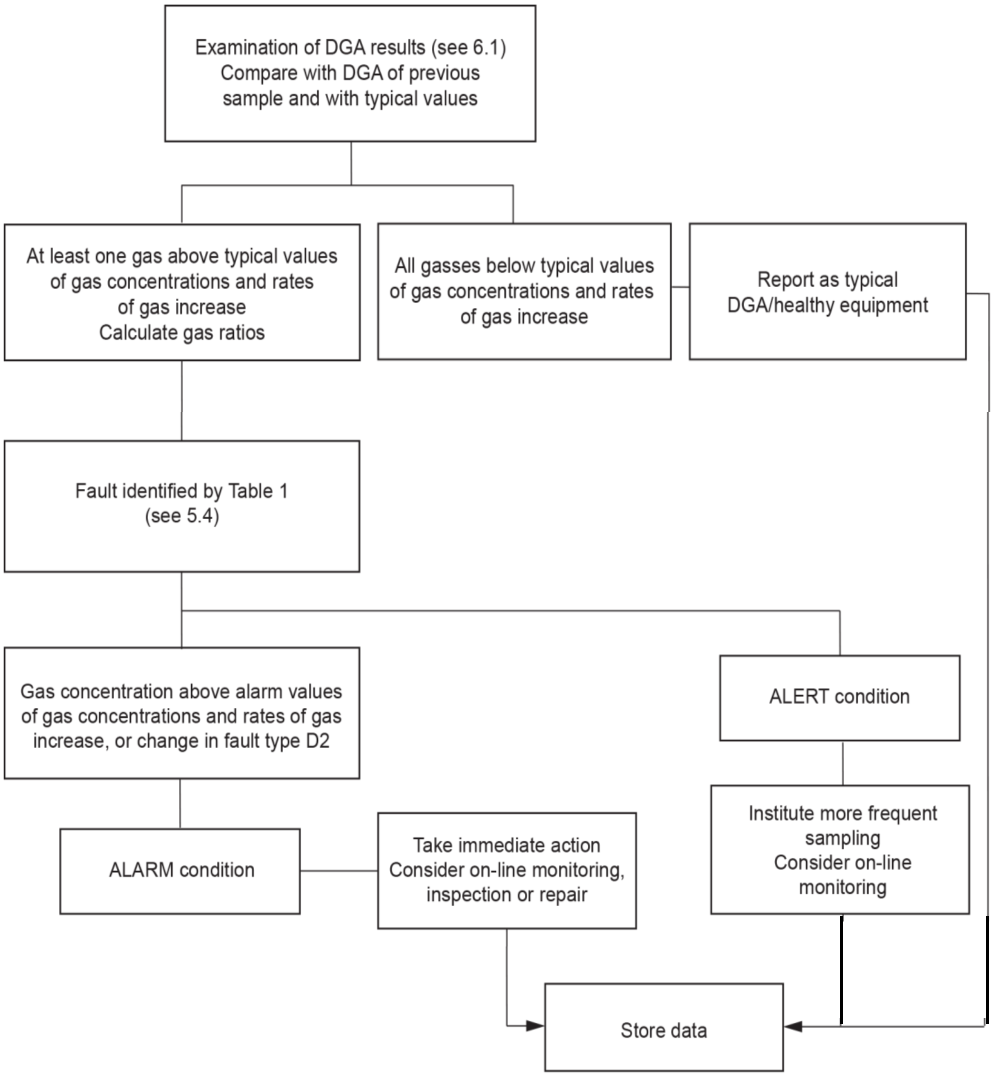

Figure 3 Flow Chart DGA Interpretation IEC 60599-2022

Interpretation using this standard is to compare the individual gas contents, namely H2, CH4, C2H6, C2H4, C2H2, CO, CO2 with a typical value. If there are one or more gas contents outside the typical value then check the rate increase of each gas. If there is an abnormal rate increase of gas, it is necessary to have further monitoring with a faster sampling frequency or other measures such as an electrical test.

The suitability of the DGA interpretation using IEC 60599-2022 with the actual condition of the power transformer is quite high, is 84%. This is because the typical value of IEC 60599-2022 is not too strict, but is also quite good at detecting any indication of abnormality in the power transformer because each individual gas has a typical value for its rates increase. In table 1 below, the accuracy value of each of these standards is written

Table 1 Accuracy of DGA Interpretation standar

IEEE C57.104-2019	CD	16/50
	WD	34/50
IEEE C57.104-2008	CD	34/50
	WD	16/50
IEC 60599-2022	CD	42/50
	WD	8/50

CD = Correct Diagnosis
WD = Wrong Diagnosis

3.5 Study Case

For example, we use data from the power transformer with manufacture years in 2013. It has a rating of 55 MVA and an operating voltage of 30/11 with an oil volume is 33000 kg. The data used is DGA data in 2017-2019. By using these data, interpretation will be made using typical values and interpretation flow based on IEEE C57.104-2019, IEEE C57.104 2008, and IEC 60599-2022. The DGA power transformer data is listed in Table 2. In table 1 below, the accuracy value of each of these standards is written

Table 2 DGA Data of Power transformer

Date	23 January 2017	05 June 2017	12 September 2017	28 August 2019
H2	<5	98	133	<4
CH4	1	10	14	<1
C2H6	<1	4	3	<1
C2H4	2	2	2	<1
C2H2	15	25	22	<1
CO	5	49	64	128
CO2	94	452	507	1214
TDCG	23	118	238	128
O2	5337	5112	5634	14074
N2	16678	11982	11369	5657
O2/N2	0.32	0.43	0.50	2.49

The DGA interpretation for the January 23, 2017 sample is as follows:

- IEEE C57.104-2019: DGA Status 3 due to acetylene gas exceeding the values in Typical Table 2 of IEEE C57.104-2019
- IEEE C57.104-2008: DGA status Abnormal because Acetylene is in condition 3.
- IEC 60599-2022: DGA status Normal because no gas content exceeds the typical value.

The DGA interpretation for the June 5, 2017 sample is as follows:

- IEEE C57.104-2019: DGA Status 3 because hydrogen gas and acetylene gas exceed the values in Table 2 of IEEE C57.104-2019 and the Delta value (difference of two consecutive samples) of hydrogen and acetylene gas exceeds the values in Table 3 of IEEE C57 .104-2019
- IEEE C57.104-2008: DGA status Normal due to value and development rate of TDCG is normal according to IEEE C57.104-2008
- IEC 60599-2022: DGA status Abnormal because Hydrogen gas rate increase exceeds the typical value of IEC 60599-2022.

The DGA interpretation for the September 12, 2017 sample is as follows:

- IEEE C57.104-2019: DGA Status 3 because hydrogen gas and acetylene gas exceed the values in Table 2 IEEE C57.104-2019 and the Delta value (difference of two consecutive samples) of hydrogen gas exceeds the values in Table 3 in IEEE C57.104 -2019 and the Gas rates for hydrogen, methane, and acetylene gases exceed the values in Table 4 IEEE C57.104-2019

- IEEE C57.104-2008: DGA status Normal due to value and development rate of TDCG is normal according to IEEE C57.104-2008 .

- IEC 60599-2022: DGA status is Normal because the individual gas content and gas rate increase do not exceed the typical values of IEC 60599-2022.

So, according to IEEE C57.104-2008 and IEC 60599-2022 active gassing has decreased which indicates an incipient fault does not exist, the owner of the transformer decided to carry out purification on November 15, 2018. One year later, the sample was taken again and gas content and gas rates are normal. It can be concluded that the gas content in the previous samples was not due to an active fault. Therefore the IEEE C57.104-2008 and IEC 60599-2022 interpretations have a better result because they more correlate with the actual condition of power transformer than IEEE C57.104-2019. It is may that IEEE C57.104-2019 can produce DGA status 1, but with several samples again, so it is less efficient.

4 Conclusion

In comparisons of interpretations based on IEEE C57.104-2019, IEEE C57.104-2008, and IEC 60599-2022, the highest percentage of conformity with actual power transformer conditions is the interpretation using IEC 60599-2022, IEEE C57.104-2008, then IEEE C57.104-2019.

This may be caused by the tightness of the typical values of IEEE C57.104-2019, especially in the value of Delta and Gas rates and also the rules for using gas rates which use 3-6 samples, making it difficult to obtain normal gas rates. Therefore there needs to be a slight adjustment to the IEEE C57.104-2019 standard.

Recommendation from author is to make typical data values that also consider the real conditions of the transformer. That is also future action from author.

Acknowledgement

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