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Use of the Dissolved Gas Analysis (DGA) Method in Identifying Problems on 2 Power Transformers 2MVA 11.5kV- 0.4kV

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ABSTRACT

Use of the DGA Method in Identifying Problems on 2 Power Transformers 2MVA 11.5kV- 0.4kV . This study discusses the application of four Dissolved Gas Analysis (DGA) methods in identifying failure indicators in power transformers. Transformer failures can occur in the form of thermal and electrical failures, producing hazardous gases known as fault gases. The insulating oil used in power transformers plays a role in cooling and dissolving these dangerous gases to prevent unrestricted circulation. Determining the type and concentration of gases dissolved in the oil can provide information about transformer failure indicators. Therefore, DGA analysis is conducted to determine effective methods for identifying these failure signs. Oil samples were taken from transformers and analyzed using four different DGA methods. The DGA analysis results revealed varying levels of gas concentration. Based on the analysis results using the Key Gas Method, Roger's Ratio Method, Doernenburg's Ratio Method, and Duval's Triangle Method, it was found that the transformers experienced thermal damage. The Duval's Triangle Method analysis concluded that two transformers had overheated. Thus, the Duval's Triangle Method analysis can be considered an effective method for identifying disturbances in power transformers due to its simple yet effective calculations.

Penelitian ini membahas penerapan empat metode Analisis Gas Terlarut (Dissolved Gas Analysis/DGA) dalam mengidentifikasi tanda-tanda kegagalan pada trafo daya. Kegagalan trafo dapat terjadi dalam bentuk kegagalan termal dan kegagalan elektrik, yang menghasilkan gas-gas berbahaya yang dikenal sebagai gas gangguan atau fault gas. Minyak isolator yang digunakan pada trafo daya berperan dalam pendinginan dan melarutkan gas-gas berbahaya tersebut agar tidak beredar secara bebas.Penentuan jenis dan konsentrasi gas yang terlarut dalam minyak dapat memberikan informasi tentang tanda-tanda kegagalan trafo. Oleh karena itu, dilakukan analisis DGA untuk mengetahui metode yang efektif dalam mengidentifikasi tanda-tanda kegagalan tersebut. Sampel oli diambil dari trafo dan dianalisis menggunakan empat metode DGA yang berbeda. Hasil analisis DGA menunjukkan tingkat konsentrasi gas yang berbeda. Berdasarkan hasil analisis menggunakan Metode Key Gas, Metode Rasio Roger, Metode Rasio Doernenburg, dan Metode Segitiga Duval, diketahui bahwa trafo mengalami kerusakan termal. Analisis menggunakan Metode Segitiga Duval memberikan kesimpulan bahwa dua trafo mengalami overheat. Dengan demikian, Metode Segitiga Duval dapat dianggap sebagai metode yang baik digunakan dalam mengidentifikasi gangguan pada trafo daya karena memiliki perhitungan sederhana namun efektif.

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1. Introduction

Along with the growth of the world's population, the demand for electrical energy is increasing. This energy is essential for both household and industrial sectors, driving the global economy. Power generation is achieved through various types of power plants worldwide, which encompass both fossil fuel-based electric generators and renewable energy power plants [1]. The majority of power plants rely on generators that produce electrical energy by utilizing the electromotive force generated from alternating windings and magnetic fields [2]. The generator produces electricity with a fairly high voltage, depending on the size of the load to be faced. The electricity generated by the generator is transmitted to the substation by power lines [3]. Electricity is distributed to the industrial and domestic sectors through electric power transmission lines. For this reason, the power supply system requires a device to increase the voltage and a device to lower the voltage, which is called a transformer [4].

There are 2 modes of using a transformer (transformer). A step-down transformer is used to lower the voltage because domestic areas require the single-phase electricity with a voltage of 220V and industrial areas require the 3-phase electricity with a voltage of 380V [4], [5]. Step-up transformers are used to increase the voltage on all power lines, for example from generators to substations and from substations to consumers [4]. This is done because the distance affects the voltage due to power loss. The longer the electric power network path, the greater the losses that occur.It is necessary to carry out tests to determine the transformer's condition to maintain the transformer's reliability one of which is by conducting a DGA (Dissolved Gas Analysis) test [6]. The DGA (Dissolved Gas Analysis) test method will determine the type and amount of decomposed gas that arises. The DGA (Dissolved Gas Analysis) test results are concentration data of various disturbance gases, which will then be analyzed and processed to obtain information on thermal and electrical failure indicators in power transformers [7].

Therefore it is necessary to identify problems or disturbances in the transformer with the DGA (Dissolved Gas Analysis) test so that later it can be determined whether there is a failure or disturbance in the transformer, by analyzing transformer failures based on the results of the DGA (Dissolved Gas Analysis) test using 4 methods: Key Gas , Roger Ratio, Doernenburg Ratio, Duval Triangle [8]. The data for early research is secondary data in the form of gas dissolved in transformer oil when the transformer is operating, with the unit value of ppm (parts per million). These data were obtained from PT. Energi Listrik Batam.

2. Literature Review

Maintenance of high voltage electrical equipment is a series of operational activities or processes that maintain conditions and ensure equipment can function properly to avoid interference causing damage [9]. The maintenance of voltage equipment is to ensure the distribution of electric power is always active and has a guarantee of reliability, including reduces downtime due to frequent interruptions, improve reliability, availability and efficiency, reduces the risk of equipment failure or damage, to extend the life of the device, & Increase device security. The most important thing in the maintaining of high voltage equipment is insulation system, includes solid insulation (hard) and liquid insulation oil) [10]. A device will be very expensive if the isolation is very high, so isolation is the most important part and determines the age of the device. For this reason, treatment or the best insulation system maintenance is required both for performance insulation as well as for the cause of damage to the insulation. Under maintenance, High voltage electrical equipment needs to be differentiated between inspections or monitoring (see, record, feel and hear) in operating and maintenance conditions (testing, calibration or reset and repair). And in no working condition [9].

2.1 Power Transformator

A transformer is a means of converting electric voltage without changing the frequency in the transmission or distribution circuit [4], [11]. The transformer's function is only to increase and decrease the voltage and does not have moving components such as electric motors or generators. The transformer principle utilizes the concept of electromagnetic inductance with two primary and secondary coils, each coil has self-inductance followed by mutual inductance between the windings [12].

2.2 Dissolved Gas In Transformer Oil

In the transformer components there is transformer oil which functions as an insulator containing complex hydrocarbon molecules such as CH_3, CH_2 and CH molecules that are linked together [13]. Breaking of some bonds between C-H and C-C elements due to thermal or electrical disturbances will produce ionic fragments such as H*, CH*, CH_{32}*, CH* or C*, which will then combine and produce gas molecules such as hydrogen (H_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4) atau acetylene (C_2H_2) [14], [15].

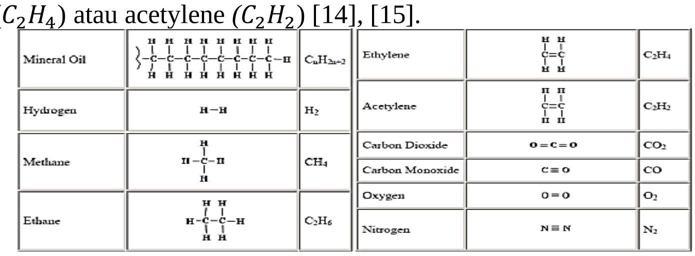


Figure 2.1. Structure of dissolved gases in insulating oil.

The higher the number of carbon bonds one to three atomic bonds in the figure 2.1, the more energy it takes to make them. hydrogen (H_2), methane (CH_4) and ethane (C_2H_6) are formed by low-energy depletion phenomena, such as partial discharges or coronas. ethylene (C_2H_4) is formed by heating oil over medium heat and acetylene (C_2H_2) is formed at very high temperatures.Other gases, such as nitrogen (N_2) and oxygen (O_2) may also be present in oil [15], [16]. Nitrogen appears due to nitrogen residues sending transformers or due to nitrogen blankets. Excessive oxygen in the transformer fan indicates a leak in the transformer tank. When there is a reduction in the amount of oxygen in the oil it will also cause the transformer temperature to rise drastically [17]. Other causes of transformer damage are water and dew from atmospheric fog due to low environmental temperatures when the transformer is not turned on. This underlies the importance of evaluating and testing the gas in the transformer to find out whether the gas is part of the problem and the percentage of transformer failure.

2.3 DGA (Dissolve Gas Analysis)

DGA means that the transformer condition analysis is based on the amount of gas dissolved in the transformer oil [18]. DGA is also known as transformer blood thesis. Human blood is in compounds that easily dissolve other substances around it. By studying the substances dissolved in the blood, we get information about human health. Similar to a transformer, testing for dissolved gases in transformer oil can also have a function to detect whether the performance and condition of the transformer is still suitable or not. [19]. To evaluate the performance of a transformer, whether the transformer is in good condition or not, one way is to check the gas extracted from the transformer oil sample, which is called DGA (Dissolved Gas Analysis) [20]. The extracted gas is then separated into gas units and calculated in ppm (parts per million). Early transformer failure can be detected by the DGA test.

3. Research Method

3.1 Design

This research begins with a literature review which includes identifying the problem, defining the problem, and then making observations related to the research object. object, the researcher takes a test sample and interprets the experimental data as well as the final conclusions that can be drawn from the tests we carry out.

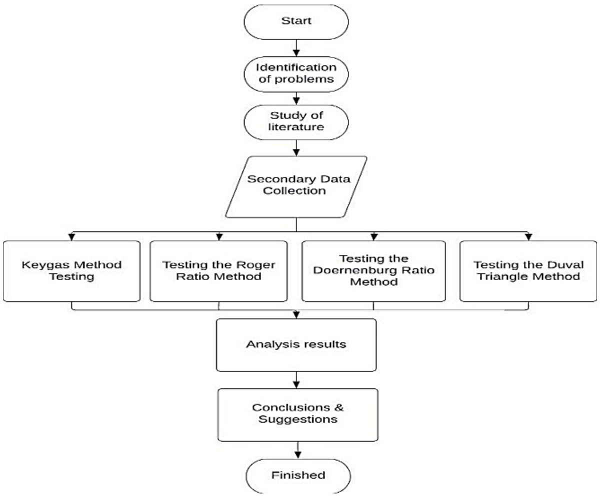


Figure 3.1. Research flow chart

3.2 Several DGA methods are used

3.2.1. Key Gas

According to IEEE Regulation C57.104-2019, the definition of Key Gas is the gas produced in an oil-filled transformer that can be used for qualitative determination to indicate the type of failure, based on the typical or dominant gas at various temperatures [6], [18]. IEEE C57.204-2019 is explained as follows:

- Thermal Mineral Oil

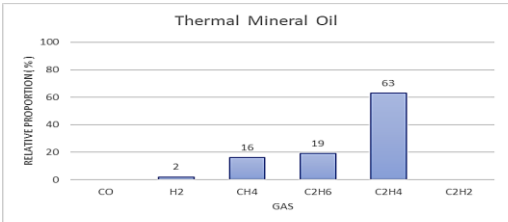


Figure 3.2 Oil Temperature Indication

Based on Figure 3.2, the decomposition of gases including ethylene (C_2H_4) and methane (CH_4) uses small quantities of hydrogen (H_2) and ethane (C_2H_6). With the emergence of acetylene gas (C_2H_2), a fault can occur severely or be followed by electrical contact. The gas is mostly dominated by ethylene (C_2H_4).

- Thermal Mineral Oil and Cellulose

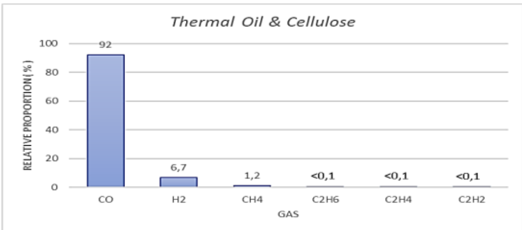


Figure 3.3 Cellulose Temperature Indication

Based on Figure 3.3, the amount of carbon monoxide (CO) is involved in the heating effect of cellulose. Hydrogen (H_2), methane (CH_4), and ethylene (C_2H_4) gases are formed when disturbances are associated with the transformer oil structure. Most of the gas is dominated by carbon monoxide (CO).

- Electrical – Low Partial Discharge

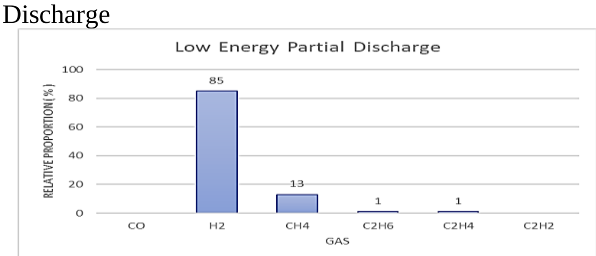


Figure 3.4 Indication of a jump in electric charge

Based on figure 3.4, low energy discharge produces hydrogen (H_2) and methane (CH_4) together with small amounts of ethane (C_2H_6) and ethylene (C_2H_4). The amount of carbon monoxide (CO) is the result of the release of cellulose. Most of the gas is dominated by hydrogen (H_2).

- Electrical – High Energy Arching

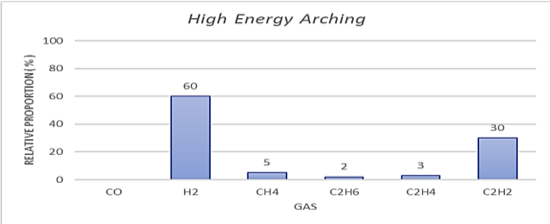


Figure 3.5 flowing electrical indication

According to figure 3.5 hydrogen (H_2) and acetylene (C_2H_2) are produced and some methane (CH_4) and ethylene (C_2H_4) are produced. carbon monoxide (CO) will always be formed if there is a failure of cellulose. Oil can be carbonized. Most of the gas is dominated by hydrogen (H_2) and acetylene (C_2H_2).

3.2.2. Roger Ratio

This Roger's ratio method compares the value of the ratio of gases to one another [21]. The gas ratios used in Roger's ratio analysis are $CH_4 \div H_2$ known as R1, $C_2H_2 \div C_2H_4$ known as R2, $C_2H_4 \div C_2H_6$ known as R5. Based on the IEEE C57.104-2019, Roger Ratio has no special requirements, so the Roger Ratio can be used directly [22].

Table 3.1 Standard Roger Ratio

Case	R1	R2	R5	Diagnose Posible Failures
0	0,1 to 1,0	<0,1	<0,1	Unit Normal
1	<0,1	<0,1	<0,1	Low-Energi Density Arcing-PD
2	0,1 to 1,0	0,1 to 3,0	>0,3	Arching-high Energy Discharge
3	0,1 to 1,0	<0,1	0,1 to 3,0	Low Temperature Thermal
4	>0,1	<0,1	0,1 to 3,0	Thermal <700 ºC
5	>0,1	<0,1	>0,3	Thermal >700 ºC

3.2.3. Doernenburg Ratio

The Doernenburg ratio method is one way to analyze decomposed gas from transformer oil. The method is similar to Roger's ratio but uses only three diagnoses. Moreover, the gas concentrations used in the calculation of the Doernenburg ratio are: R1 = CH_4/H_2, R2 = C_2H_2/C_2H_4, R3 = C_2H_2/CH_4, R4 = C_2H_6/C_2H_2 [23]. This Doernenburg Ratio has two conditions to ensure Doernenburg data, namely:

1) If either of the gas concentrations for H_2, CH_4, C_2H_2, abd C_2H_4 exceeds 2 times the limit value of L1 and one of the other two gases (CO and C_2H_6) exceeds the limit value of L1 [24].
2) Determining the validity of the ratio: at least one gas in the ratio R1, R2, R3, or R4 exceeds the L1 limit value, and if not, the oil sample will be re-taken [24].

Table 3.2 Doernenburg L1 Concentration Gas Data [25]

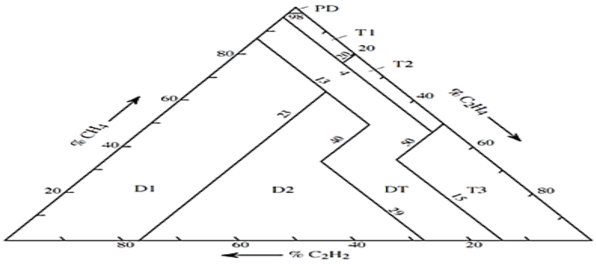
Parameter Gas	**L1 Concertration (ppm)**
Hydrogen (H2)	100
Methane (CH4)	120
Carbon Monoxide (CO)	350
Acetylene (C2H2)	1
Ethylene (C2H4)	50
Ethane (C2H6)	65

Table 3.3 Doernenburg Ratio standard [25]

Diagnostic Failure cases	R1 CH4/H2 Extracted From		R2 C2H2/C2H4 Extracted From		R3 C2H2/CH4 Extracted From		R4 C2H6/C2H2 Extracted From	
	Mineral Oil	Gas Space	Mineral Oil	Gas Space	Mineral Oil	Gas Space	Mineral Oil	Gas Space
Thermal Decomposition	>0,1	>0,1	<0,75	<0,1	<0,3	<0,1	>0,4	>0,2
Corona (Low Intensity PD)	<0,1	<0,01	Not Significant		<0,3	<0,1	>0,4	>0,2
Arching high Intensity PD)	>0,1 & <0,1	>0,01 & <0,1	>0,75	>0,1	>0,3	>0,1	<0,4	<0,2

3.2.4. Duval Triangle

The Duval Triangle method uses three gases that correspond to increasing energy content: (CH_4) for low energy or low temperature problems, ethylene (C_2H_4) for high temperature problems, and acetylene (C_2H_2) for high energy or high temperature or arching faults. The total concentration of these three gases is 100%, but a change in the composition of these three gases indicates a possible failure in the equipment under test.



Fault Gas	Description
T1	Thermal Fault, temperature under 300 °C
T2	Thermal Fault, temperature under 300 °C and temperature under 700 °C
T3	Thermal Fault, temperature over 700 °C
DT	Thermal & Electric
PD	Partial Discharge
D1	Discharge Low Energy
D2	Discharge High Energy

Figure 3.2.5 Indications of the Duval Triangle method & Duval Triangle Gas Fault Description

To present DGA results in the Duval Triangle, starting from the concentrations of the three gases is necessary. (CH_4) for the A value, (C_2H_4) for the B value and (C_2H_2) for the C value, in ppm (parts per million). First, calculate the total value of these three values: (CH_4+ C_2H_4+ C_2H_2) as the S value, in parts per million (ppm), then calculate the relative proportion of the three gases, in percentage value, X Value = %CH_4 = 100% (Value A ÷ Value S), Y Value = %C_2H_4 = 100% (Value B ÷Value S), and Z Value = %C_2H_2 = 100% (Value C ÷ Value S).

The X, Y, and Z values must be between 0 and 100%, and (X + Y + Z) = 100%. The X, Y, and Z values for Triangle give only one point for Triangle. For example, if the DGA result is C = B = A = 100 ppm, Z = Y = X = 33.3%, it corresponds to a point in the center of the triangle. If the coordinates of the three gases are in the PD area, a partial discharge has occurred. Area T1 indicates thermal failure at temperatures below 300° C and Area T2 indicates thermal failure between 300° C and 700° C. Area D1 indicates low energy release (spark) and area D2 indicates high energy release (electric arc). The DT area is a combination of thermal and electrical failures.

4. Result and Discussions

4.1 Objects and Study Areas

There are 2 power transformer objects that will be studied as power plants located in the Batam, Tanjung Uncang area. The specifications of the transformer tested are as follows:

Table 4.1 Transformator Specification

Data Specification	*Transformator* SST1B	*Transformator* TX1A
NO *Transformator*	D14, 05, 0054	D14, 05, 0077
Nominal Rating (kVA)	2000	1250
Nominal Voltage (kV)	Primary : 11,5 & Secondary : 6,6	Primary : 6,6 & Secondary : 0,4
Nominal Current (A)	Primary : 100,4 & Secondary : 175	Primary : 109,3 & Secondary : 180,42
Cooling	ONAN	ONAN
Type Oil	Mineral Oil	Mineral Oil
Oil Weight (kg)	1160	295

4.2 SST1B Transformer Data Interpretation

The parameters in the data are the concentration values of the various types of disturbance gases: hydrogen (H_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_2), and carbon monoxide (CO).

Table 4.2 SST1B Transformer Gas Parameter Table

Parameter Gas	Unit	Standar	Value
Hydrogen (H2)			227
Methane (CH4)			42
Carbon Monoxide (CO)			25
Carbon Dioxide (CO2)	ppm	IEC 60567	429
Acetylene (C2H2)			0,24
Ethylene (C2H4)			58
Ethane (C2H6)			13

4.2.1. Key Gas Method

The first thing that must be done in using the Key Gas method is to determine the percentage of each gas, after that the following percentages are obtained:

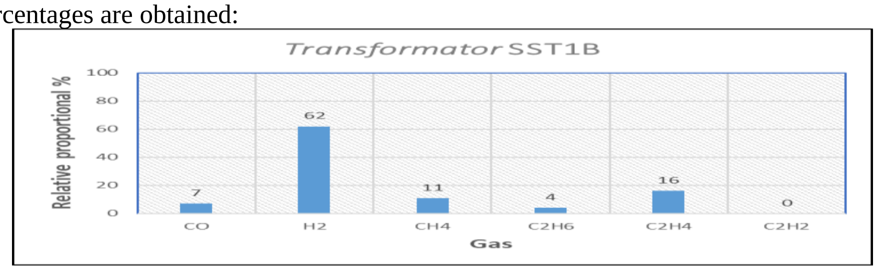


Figure 4.1 Keygas SST1B chart

Based on Figure 4.1, it can be seen that the dominant gases in the test are hydrogen (H_2) and ethylene (C_2H_4) with values of 62% and 16%. Based on the data and the IEEE C57.104-2019 standard, the SST1B transformer has failed to discharge electrically (Low Energy - Partial Discharge).

4.2.2. Roger Ratio Method

The Roger Ratio method compares 5 types of gas concentrations, namely: methane (CH_4), hydrogen (H_2), acetylene (C_2H_2), ethylene (C_2H_4), ethane (C_2H_6).

$$R1 = \frac{CH_4}{H_2} = \frac{42}{227} = 0{,}18 \qquad R2 = \frac{C_2H_2}{C_2H_4} = \frac{0{,}24}{58} = 0{,}004 \qquad R5 = \frac{C_2H_4}{C_2H_6} = \frac{58}{13} = 4{,}46$$

After the comparison values of the gases are obtained, they are entered into the Roger's Ratio which is shown in Table 3.1. Code R1 R2 R5 indicates that the value does not match the table, so the value cannot be entered in the standard table (not available or invalid).

4.2.3. Doernenburg Ratio Method

The Doernenburg Ratio method compares 5 types of gas concentrations, namely: methane (CH_4), hydrogen (H_2), acetylene (C_2H_2), ethylene (C_2H_4), ethane (C_2H_6).

$$R1 = \frac{CH_4}{H_2} = \frac{42}{227} = 0{,}18 \quad R2 = \frac{C_2H_2}{C_2H_4} = \frac{0{,}24}{58} = 0{,}004 \quad R3 = \frac{C_2H_2}{CH_4} = \frac{0{,}24}{42} = 0{,}005 \quad R4 = \frac{C_2H_6}{C_2H_2} = \frac{13}{0{,}24} = 54{,}1$$

After the comparison value of the gases is obtained, it is entered into the Doernenburg ratio shown in table 3.3 Code R1 R2 R3 R4 shows in case 1 that is thermal decomposition. There is an indication of overheating on the wire insulation layer. It can cause CO gas because it is glued with a layer of cellulose insulator. This condition reduces the dielectric strength of the insulating oil.

4.2.4. Duval Triangle Method

The Duval Triangle method uses 3 gas concentration values, namely: methane (CH_4), ethylene (C_2H_4), and acetylene (C_2H_2). Based on Figure 4.2, it can be concluded that there is an indication of thermal disturbance with temperatures greater than 700°C. It can be seen that the midpoint of these 3 types of gases is in the T3 area.

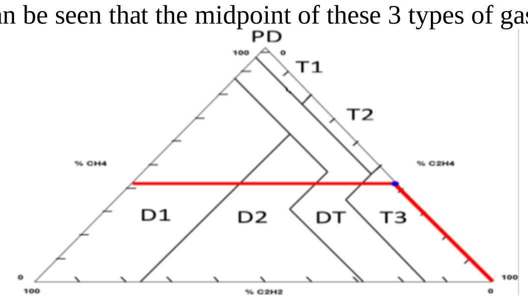


Figure 4.2 Results of Analysis of the Duval Triangle Method of Transformer SST1B

4.3 TX1A Transformer Data Interpretation

4.3.1. Key Gas Method

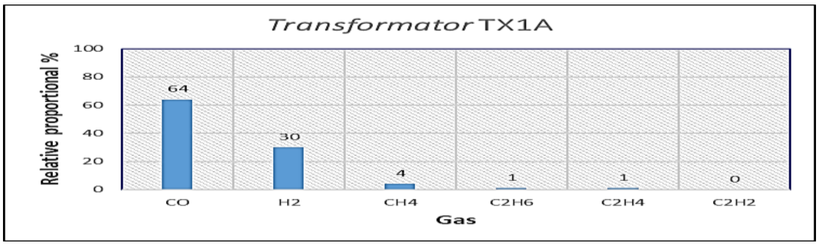


Figure 4.3 Keygas TX1A chart

Based on Figure 4.2.1, it can be seen that the dominant gases in the DGA test were carbon monoxide (CO) and hydrogen (H_2) with values of 64% and 30%. Based on data and IEEE C57.104-2019 standards, the TX1A transformer experiences thermal mineral cellulose failure or overheating

4.3.2. Roger Ratio Method

The Roger Ratio method compares 5 types of gas concentrations, namely: methane (CH_4), hydrogen (H_2), acetylene (C_2H_2), ethylene (C_2H_4), ethane (C_2H_6).

$$R1 = \frac{CH_4}{H_2} = \frac{25}{200} = 0{,}125 \quad R2 = \frac{C_2H_2}{C_2H_4} = \frac{0{,}24}{8} = 0{,}03 \quad R5 = \frac{C_2H_4}{C_2H_6} = \frac{8}{5} = 1{,}6$$

After the comparison value of the gases is obtained, it is entered into the Roger Ratio shown in Table 3.1. Code R1 R2 R5 indicates in case 3 that there is an indication of low thermal temperature on the wire insulation layer. It can cause CO gas because it blends with the cellulose insulating layer. This condition reduces the dielectric strength of the insulating oil

4.3.3. Doernenburg Ratio Method

The Doernenburg Ratio method compares 5 types of gas concentrations, namely: methane (CH_4), hydrogen (H_2), acetylene (C_2H_2), ethylene (C_2H_4), ethane (C_2H_6).

$$R1 = \frac{CH_4}{H_2} = \frac{25}{200} = 0{,}125 \quad R2 = \frac{C_2H_2}{C_2H_4} = \frac{0{,}24}{8} = 0{,}03 \quad R3 = \frac{C_2H_2}{CH_4} = \frac{0{,}24}{25} = 0{,}0096 \quad R4 = \frac{C_2H_6}{C_2H_2} = \frac{5}{0{,}24} = 20{,}84$$

After the comparison value of the gases is obtained, it is entered into the Doernenburg ratio shown in Table 3.3. Code R1 R2 R3 R4 shows in case 1 namely thermal decomposition and an indication of overheating in the wire insulation layer. It can cause CO gas and CO_2 because it blends with the cellulose insulator layer. This condition reduces the dielectric strength of the insulating oil.

4.3.4. Duval Triangle Method

The Duval Triangle method uses 3 gas concentration values, namely: methane (CH_4), ethylene (C_2H_4), and acetylene (C_2H_2). Based on Figure 4.4, it can be concluded that there is an indication of thermal disturbance with temperatures reaching from 300°C to 700°C. It can be seen that the midpoint of these 3 types of gases is in the T2 area.

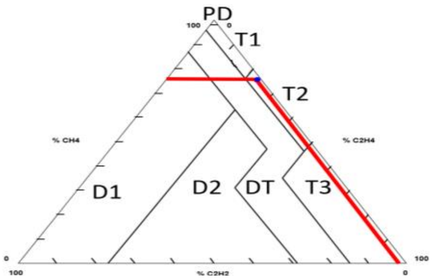


Figure 4.4 Results of Analysis of the Duval Triangle Method of Transformer TX1A

4.4 Results of SST1B and TX1A Transformer Data Analysis

Table 4.3 DGA Test Data Analysis Results

Transformer	Analysis Method	DGA Analysis Results
SST1B	Keygas	Low Energy – Partial Discharge
	Roger Ratio	Not Available-invalid
	Doernenburg Ratio	Thermal Decomposition
	Duval Triangle	Thermal Fault more than 700° C
TX1A	Keygas	High Energy - Arching
	Roger Ratio	Low Temperature Thermal
	Doernenburg Ratio	Thermal Decomposition
	Duval Triangle	Thermal Fault 300° C - 700° C

1. The analysis results obtained in Table 4.3 show that the condition of the SST1B transformer indicates a Thermal Fault >700°C. Several possible fault causes include overload, eroded insulation between adjacent conductors in the winding. When the temperature is >700°C, significant carbon particle formation can occur in the oil and the oil discoloration becomes metallic or metal agglomeration.
2. The analysis results obtained in Table 4.3 show that the condition of the TX1A transformer unit has a Thermal Fault indication of <300°C-700°C. Several possible >700°C include overload, eroded insulation between adjacent conductors in the winding. Appearance in oil when temperature >200°C becomes brown and at temperature >300°C carbon particles are formed in the oil.

5. Conculusion

Based on the final task analysis, the following conclusions can be drawn the Key Gas method has the advantage of being able to deduce indications of disturbances in the transformer using graphic images. However, the weakness is that the graphic images obtained from the test results are not the same as the IEEE C57.104-2019 standard. The Roger and Doernenburg ratio methods can be used to determine transformer disturbances. However, the weakness of this method is that it uses calculations and values specified in the IEEE C57.104-2019 standard table. The Duval Triangle method is the most appropriate method to use because it can infer faults in a transformer with simple and powerful calculations, and all types of fault indications can be detected in closed zones. Indication of Fault in 2 transformers experiencing thermal failure overheating.

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