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Partial Discharge Analysis of UBJOM Rembang PLTU Using Roger's Ratio Method

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Abstract

The disturbance of transformers often occurs at the field is named partial discharge. It refers to the spark release in the isolation of internal cavity or surface caused by the potential difference in the transformer isolation. As a result, the quality degradation of isolation material happens. To test it, the researcher employed Dissolved Gas Analysis by Roger's Ratio and Duval Triangle methods. The results demonstrated that transformer GT 10 reached the highest temperature of 417,229^{0}C and produced overheating as indicated by paper carbonation and carbon particle formation in the oil (thermal fault 3000C–7000C). Meanwhile, the GT 20 transformer achieved the highest temperature of 169.2307^{0}C and the color of paper isolation change to brown (at <300°C). Both transformers were detected getting the failure of partial discharge as the temperatures were more than 150^{0}C; in which several gases were formed, including hydrogen and methane gases at around 150^{0}C, ethane gas at approximately 250^{0}C, ethylene gas at about 350^{0}C, and acetylene gas at around 700^{0}C. Accordingly, the higher the temperature, the lower the dielectric capacity, where it should function for separating the electrical conductors.

Keywords: *Transformer, Partial discharge detection method, Duval triangle, Transformer isolation, Roger's ratio*

Abstrak

Gangguan transformator yang sering terjadi di lapangan adalah partial discharge, yaitu pelepasan bunga api pada isolasi bagian rongga dalam ataupun permukaan, yang disebabkan adanya beda potensial pada isolasi transformator, sehingga menyebabkan penurunan kualitas (degradasi) dari bahan isolasi. Untuk itu, salah satu cara pengujiannya menggunakan Dissolved Gas Analysis dengan metode Roger's Ratio, dan Duval Triangle. Dari hasil pengujian, didapatkan bahwa transformator GT 10 mencapai temperatur tertinggi sebesar 417,229 ℃ sehingga terjadi overheating, yaitu karbonasi kertas, munculnya formasi partikel karbon pada minyak (thermal fault 3000C – 7000C), sedangkan transformator GT 20 mencapai temperatur tertinggi pada 169,2307 ℃, sehingga terjadi perubahan warna isolasi kertas menjadi coklat (pada temperatur <300°C). Kedua transformator tersebut terdeteksi mengalami kegagalan partial discharge, hal ini dikarenakan suhunya melebihi 150 ℃, sehingga akan terbentuk gas hidrogen dan metana, di mana gas hidrogen dan metana mulai terbentuk pada suhu sekitar 150 ℃, sedangkan gas etana terbentuk pada suhu sekitar 250 ℃, gas etilen pada suhu sekitar 350 ℃, dan gas asetilen pada suhu sekitar 700 ℃, di mana semakin tinggi temperatur, semakin menurun kemampuan dielektrik yang seharusnya berfungsi untuk memisahkan penghantar listrik.

Kata-kata kunci: *Transformer, Metode partial discharge detection, Duval triangle, Transformer isolation, Roger's ratio*

1. Introduction

A transformer is an electrical device of which function is to transfer power from high voltage to low voltage and vice versa, which has safety parts such as insulators [1]. The transformer works based on the working principle of magnetic induction, which simultaneously induces an iron core, then the magnetic flux formed in the iron core cuts the primary coil and produces magnetic flux, causing the secondary coil to produce a potential difference [2].

After the power transformer is loaded, the oil will absorb the heat in the system, and then guide it out of the system with the help of the transformer heat sink; if the transformer is loaded and operated continuously, it can cause Partial Discharge (PD) [3]. In this study, Partial Discharge testing was carried out on the transformer using the Roger's Ratio method, in order to determine the condition of the fluid in the transformer insulator. If partial discharge occurs continuously, excessed heat will be generated to the transformer insulator, which will damage the insulating material and cause system failure. The Roger Ratio method is a method for analyzing the gas that decomposes from transformer oil by comparing the two gases being tested, then converting the data into digital codes according to IEEE rules. The digits of the code unveil the condition of the transformer, whether it is in good or bad conditions.

In this study, Partial Discharge testing was carried out on transformers using the Roger's Ratio method to determine the health of the transformer insulator of the UBJOM Rembang PLTU, so that there is no damage that results in fatal losses or damage to the transformer. Roger's ratio method is a gas analysis method decomposed in transformer oil. This method compares the value of one gas with the value of another gas.

A transformer is an electrical device that can transfer and convert electrical energy from one circuit or more circuits to another. In general, transformers are divided into two types: step-up transformers to increase the voltage and step-down transformers to reduce voltage [4]. Insulating oil has two main functions, namely, an insulating medium and a cooling medium [5]. An insulator is a material feature that can separate two or more adjacent conductors to prevent current leakage/short circuit, and provide mechanical protection to prevent corrosion or voltage damage. Insulating oil used in power transformers has several main tasks namely: Media insulator, Cooling medium, Arc extinguisher/media, and Prevents corrosion or oxidation.

Oxidation of the transformer oil occurs due to an increase in the drive temperature. With the increase in the load on the transformer, the chemical reactions that occur in the transformer oil will be faster, and the acid content will be higher. As the acid content in the oil increases, the quality of the oil decreases. To find the temperature value, the following IEEE formula can be used:

$$T\ ºC = \left(100 \times \frac{C_2H_4}{C_2H_6}\right) + 150 \quad (1)$$

In the insulation oil specification and maintenance guide SPLN 49-1, it is stated that transformer insulation oil must meet certain specifications so that the insulation process with transformer oil can be carried out optimally [6]. Table 1 shows the transformer oil specifications according to SPLN 49-1: 1982.

Table 1. Transformer Oil Specification Standard [7]

No.	Parameter	Limitation
1	Breakthrough Voltage	• 50 kV/2.5 mm for voltage > 170 kV • 40 kV/2.5 mm for voltage 70 kV – 170 kV • 30 kV/2.5 mm for voltage < 70 kV
2	Water content	• <20 mg/1 for >170 kV • <30 mg/1 for <170 kV
3	Dielectric Leakage Factor	<0.2 to 2.0
4	Prisoner Type	1G m
5	Neutrality score	<0.5 mg KOH/gt
6	Sediment	Not measurable
7	Flash point	Maximum drop 15°C
8	Surface tension	>0.015 N/m

Relative gas concentration according to IEEE is presented in Figure 1.

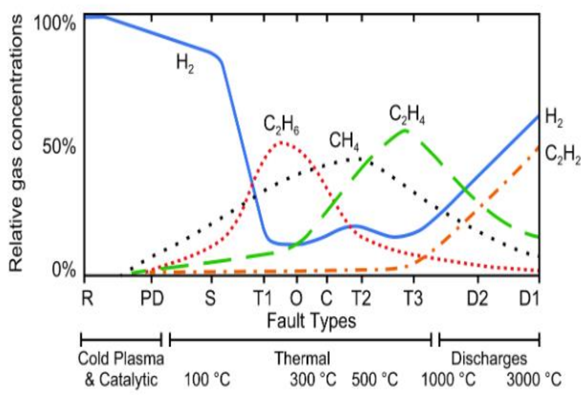

Figure 1. Relative Gas Concentration According to IEEE [1]

In Figure 1, it is explained that the problem has been shown according to the temperature that occurs in the transformer: at temperatures below 100°C, cold plasma & catalytic occurs;

between 100°C up to 1000°C, Partial discharge occurs to overheating; and at 1000°C up to 3000°C, discharge occurs. Formation of fault gas based on temperature is presented in **Figure 2**.

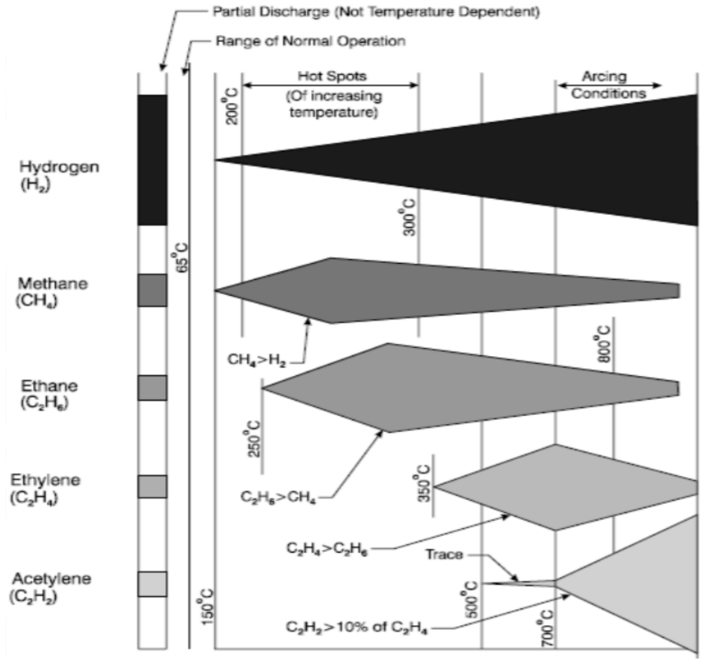

Figure 2. Formation of Fault Gas based on Temperature **[8]**

Figure 2 explains the formation of fault gas and its concentration when the temperature rises. Hydrogen and methane gas begin to form at a temperature of about 150°C. Ethane gas begins to form at 250°C. Ethylene gas forms at a temperature of about 350°C. Acetylene gas appears at a temperature of about 700°C. The concentrations of ethane and ethylene gases indicate the cause the occurrence of interference with molten iron, while acetylene in large quantities will cause an electric arc (internal electric arc). At the same time, hydrogen, methane, and ethane can cause signs of partial discharge or corona. Partial Discharge is "partial discharge, which only partially bridges the insulation between the conductors and may or may not occur around the conductors." Partial discharge of an insulated part or part of a conductor to the surface or interior is called partial discharge. Partial Discharge is an event in which an electric spark (spark) is released/reflected on the insulator in the inner cavity of the insulator and the surface of the insulating material due to a very high potential difference in the insulator. Partial discharge can also be defined as a result of concentrated electrical stress within or on the surface of the insulator **[9]**.

Insulation disturbances in the form of partial discharge (usually liquid insulation) produce dangerous gases which are commonly referred to as fault gases. Most bushings use insulating oil, which is used as a refrigerant and solvent for harmful gases, so they cannot circulate freely.

Identifying the type and amount of dissolved gas concentration in the oil can provide information on indications of disturbance (such as local emissions). The method of identification and analysis of dissolved gases is called Dissolved Gas Analysis (DGA). Here's how to test DGA [10] [11].

a. Gas chromatography

Gas chromatograph is a technique for separating certain substances from compounds, usually these substances are separated according to the rate of evaporation.

b. Photoacoustic spectroscopy

The measurement process using the PAS method begins with a radiation source that produces infrared radiation from electromagnetic waves. The radiation is reflected on the parabolic mirror and then reflected onto the cutting board, the cutting board rotates at a constant speed and produces an invisible effect on the light source.

Roger Ratio Method (RRM) has a diagnostic method similar to the Doernenburg ratio method (DRM) [2].The difference lies in the accuracy and quantity of the concentration ratio to be analyzed. Gas ratio, etc. $\frac{C_2H_2}{C_2H_4}$, $\frac{CH_4}{H_2}$, $\frac{C_2H_4}{C_2H_6}$. This ratio is in the revised IEEE standard C57.104.2019. Roger ratio method code is presented in **Table 2**.

Table 2. Roger Ratio Method Code

Code	$\frac{C_2H_2}{C_2H_4}$	$\frac{CH_4}{H_2}$	$\frac{C_2H_4}{C_2H_6}$
0	<0.1	0.1 to 1.0	<1.0
1	<0.1	<0.1	<1.0
2	0.1 to 3.0	0.1 to 1.0	>3.0
3	<0.1	>1.0	1.0 to 3.0
4	<0.1	>1.0	1.0 to 3.0
5	<0.1	>1.0	>3.0

The following is a description of the above conditions:

a. Code 0, there is no indication of a disturbance in the transformer isolation oil, so the condition of the oil is still in good condition. However, the increase in other dissolved gases needs to be monitored by obtaining test samples at subsequent time intervals.

b. Code 1, because the air or oil contained in the insulation system contains a large amount of moisture, which causes the liquid to escape. In addition, it can also be caused by solid insulation caused by sparks or electric arcs or current jumps (usually causing CO and CO_2 gases).

c. Code 2, because sparks are continuously generated between the coil and the coil or between the ground and the coil during the switching period, or at the faucet switch, or the insulating oil leaks from the faucet switch tank to the main tank, so that a spark will occur generated. This situation led to a fall in the price of insulating oil dielectrics.

d. Code 3, overheating occurs in the insulating layer of the wire, usually causing CO and CO_2 gases, because it involves the cellulose insulation layer.

e. Code 4, the transformer core is overheating. The core laminate is short-circuited. Overheating is caused by eddy currents. The input terminal side is not connected properly, or the faucet switch is touching. Current circulates between the transformer core and ground.

f. Code 5 is the same as Code 4, it's just that the disturbance that occurs will damage the cellulose insulation and cause CO and CO2 gases.

The limitation of the Roger Ratio method is that it cannot identify errors in a small range. Since it is not suitable for any situation, there is an error even though it is obvious.

Duval triangle method **b**y interpreting the data obtained through various existing methods, the casing condition is analyzed based on the results of the DGA test. However, to pay more attention to the partial discharge (PD) phenomenon that occurs in the casing, a "Duval Triangle" analysis was carried out. It is easy to see if the PD phenomenon has occurred. This method was proposed by Michael Duval in 1974. It only considers the specific conditions of concentration of methane (CH_4), ethylene (C_2H_4) and acetylene (C_2H_2). The sum of these three gases is 100%. Changes in the composition of these three gases indicate a state of failure phenomena that may occur in the test casing. The Duval method uses concentrations of three main gases to diagnose the condition of oil as an insulating agent, namely CH_4, C_2H_4 and C_2H_2. If the coordinates of the three air bonds are in the PD area, it means that a partial release has occurred. Area T1 shows thermal failure when the temperature is lower than 300°C, and T2 shows thermal failure when the temperature is between 300°C and 700°C. D1 means low energy release (spark), D2 means high energy release (arc).

The DT area represents the combined heat failure is presented in Figure 3.

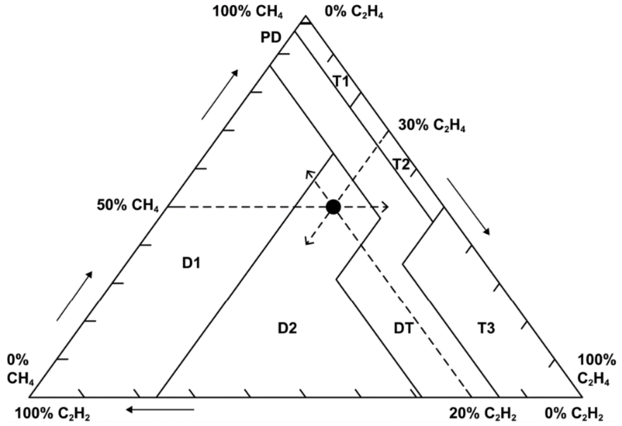

Figure 3. DT Area

2. Method

This stage aims to clarify the results of the processing of this analysis which were then used to determine the type of gas dissolved in the transformer oil produced from the type and quality of the oil in the transformer. The data collected were then processed through calculations and analysis in order to obtain the parameters contained in the Roger's Ratio method. The following are the steps of the Roger's Ratio method is presented in Figure 4.

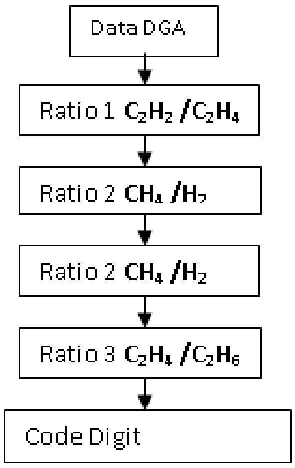

Figure 4. Flowchart Roger's Ratio

From the data obtained to determine the percentage of gas value for analysis using the Duval triangle method, you can use the following steps is presented in Figure 5.

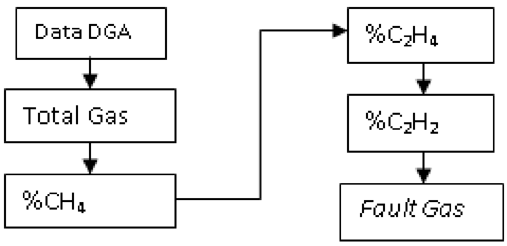

Figure 5. Flowchart Duval Triangle

3. Results and Discussion

Figure 6 is a graph of the temperature of the GT 10 transformer and GT 20 transformer with the highest temperature of above 450℃ for the GT 10 transformer and around 160°C for the GT 20 transformer, which according to SPLN 49-1, Hydrogen and methane gases begin to form at a temperature of about 150°C, Ethane gas begins to form at a temperature of 250°C, Ethylene gas forms at a temperature of about 350°C, and Acetylene gas appears at a temperature of about 700°C. The ethane and ethylene gas Concentration indicate the cause of interference in molten iron, acetylene in large quantities will cause an electric arc. At the same time, hydrogen, methane, and ethane can cause signs of partial discharge or corona.

On the GT 10 transformer shown in the Figure 6, it can be seen that there are several code numbers, the lowest is code number 3, which means the wire insulation layer is overheating which usually causes CO and CO2 gases because it involves cellulose. The highest insulation layer is at code number 5, which means the transformer core is experiencing overheating. The core laminate is short-circuited. Overheating is caused by eddy Furrents bad connection on the input terminal side, or tap the ignition switch. The current circulates between the transformer core and the ground, and causes damage to the cellulose insulation layer, and causes CO and CO2 gases. Meanwhile, the GT 20 transformer cannot be analyzed using the Rogers ratio method, according to the IEEE C57.104.2019 standard. The limitation of the Rogers ratio method is that it cannot identify errors on a very small scale because it doesn't fit in any case, even when it's obvious that there's an error, or because the measurement of gas concentration is very inaccurate, it can lead to an error in assessing the severity of the disturbance and identifying the type of error. GT 10 and GT 20 temperature transformers is presented in Figure 6.

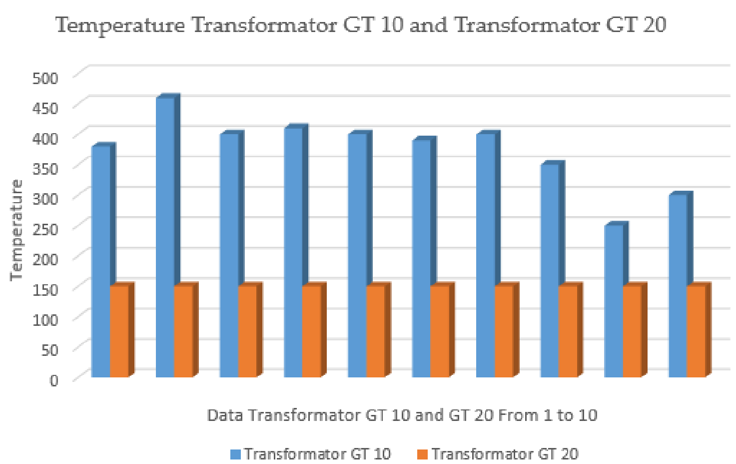

Figure 6. GT 10 and GT 20 Temperature Transformers

Several code number transformer GT 10 and GT 20 is presented in Figure 7.

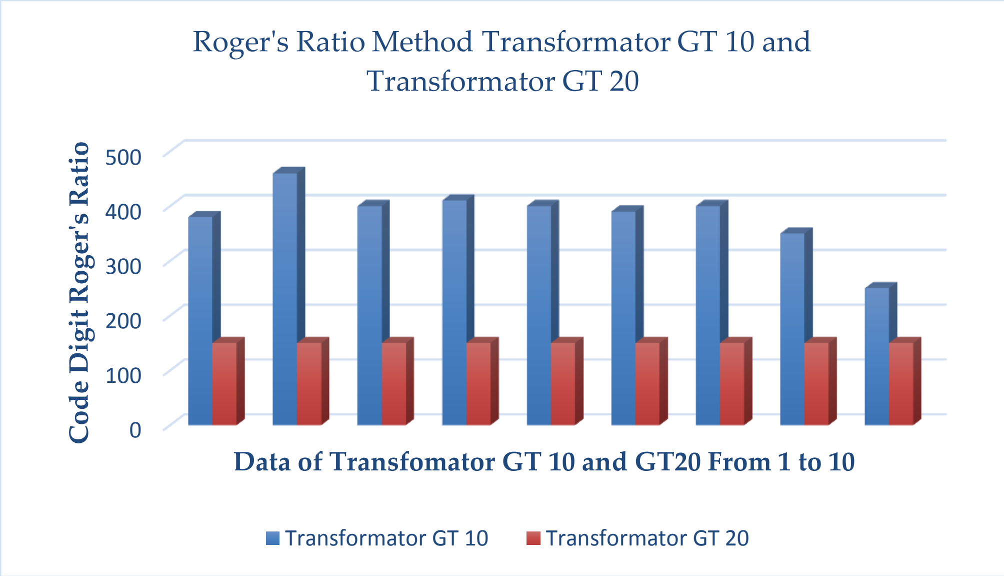

Figure 7. Several Code Number Transformer GT 10 and GT 20

Duval triange method transformator GT 10 and GT 20 is presented in Figure 8.

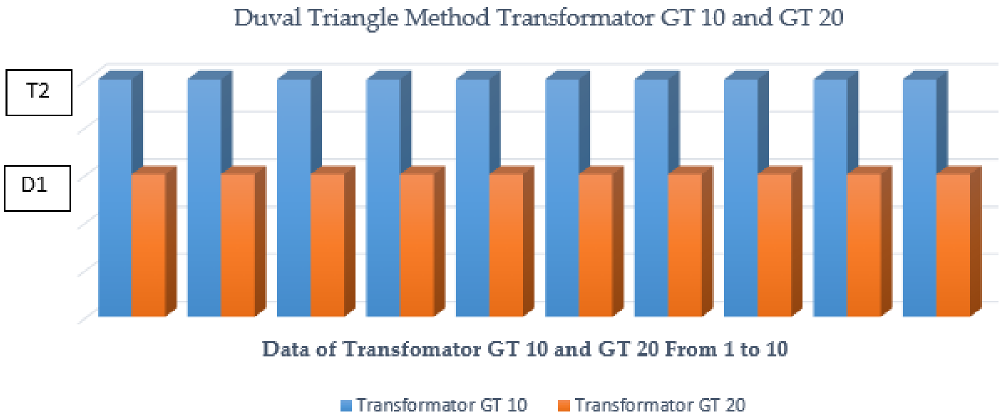

Figure 8. Duval Triange Method Transformator GT 10 and GT 20

From Figure 8, it can be concluded that for the GT 10 transformer from November 22, 2016 to November 15, 2021, the code T2 was obtained, which means a 300°C-700°C thermal fault occurred, namely paper carbonation, the appearance of carbon particle formation in GT10 transformer oil. For the GT 20 transformer, there is a Low of Energy (D1) Discharge failure, which means that the Partial Discharge of the spark type causes a larger carbon perforation in the paper insulation layer. Among other things, the low energy arc will stimulate the carbon perforation on the surface of the insulating paper, generating a large number of carbon particles in the oil (mainly due to the operation of the tap changer).

4. Conclusion

When testing with the roger's ratio method of GT 10 transformer, overheating occurs where the temperature of the transformer exceeds 300, the transformer GT 20 cannot be detected with an error code, so the Duval triangle method was used. The result of the GT 10 transformer is that at 300°C-700°C thermal fault occurs, namely paper carbonation, the appearance of carbon particle formation in the oil. For the GT 20 transformer a spark type Partial Discharge occurs which causes larger carbon perforations in the paper insulation layer. Among them, low energy arching will stimulate the carbon perforation on the surface of the insulating paper, generating a large number of carbon particles in the oil (mainly due to the operation of the tap changer).

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