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TRANSFORMER OIL PERFORMANCE TESTING USING CORRELATION COEFFICIENT METHOD

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ABSTRACT

The performance of transformer oil as a cooling insulator determines the electric power distribution system. Transformer oil should be tested regularly. The main parameters are Total Dissolved Combustible Gas (TDCG) by using Dissolved Gas Analysis (DGA) to measure the quantity of dissolved gas, Breakdown Voltage to measure the ability of oil insulate the electric voltage, and Water Content to measure the water content in the oil. This research examines the relationship between the main parameters. Four samples of transformer oil for 150 KV power indicated that initial failure occurs due to corona, arcing, and overheating of cellulose at low energy levels. The TDCG has a weak correlation to Breakdown Voltage and Water Content. The Breakdown Voltage and Water Content have a strong correlation with each other. Transformer oil testing is recommended to be conducted regularly every 3-6 months, while the replacement depends on the condition and age of the transformer oil.

Key words: Transformer Oil, Dissolved Gas Analysis, Breakdown Voltage, Water Content, Insulation Performance.

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1. INTRODUCTION

The transformer in the electric power distribution system has an important role in reducing the mains voltage before distributed to users. However, the performance of the transformer often suffers from disturbances in the power distribution process. In Jakarta, during 2018 there were 1,394 electricity matters caused by disruption of transformer performance [1]. The causes are mostly because of overloading that raises the temperature of the transformer. Excess heat reduces the life-cycle and quality of the oil as an insulator and a cooling system in the transformer [2].

Putra [3] defines that the age of an insulator is when no longer able to perform optimally, both electrically and mechanically, cause the failure of the insulation. It effects to system outage and requires high costs for repairing. These empirical facts lead to the maintenance and testing process of transformer oil is highly needed to maintain the performance of the transformer.

Setiawan [4] encouraged three main parameters for detecting the failure of transformer oil insulation. They are Dissolved Gas Analysis (DGA), Breakdown Voltage and Water Content. Dissolved Gas Analysis detects dissolved gas levels in transformer oil because the more gas content decreases the oil's insulation ability Breakdown Voltage measurement is to analyze the ability of the oil to withstand electric voltage. Measurement of Water Content in transformer oil is to analyze the water content in the oil.

This study aims to determine the relationship between the main parameters of transformer oil at 150 KV. There are four samples examined in the study. The findings are useful for transformer oil, whether it is still usable, needs to be refined, or should it be replaced.

2. MATERIAL AND EXPERIMENTAL PROCEDURES

2.1. Dissolved Gas Analysis

The dissolved gas content in transformer oil is an indicator of the lifetime and quality of the oil insulation [5]. Table 1 shows the limit of dissolved gas concentration according to the IEEE standard [6].

Table 1 Limit of dissolved gas concentration in ppm

Condition	H_2	CH_4	C_2H_2	C_2H_4	C_2H_6	CO	CO_2	TDCG*
1	100	120	35	50	65	350	2500	720
2	101-700	121-400	36-50	51-100	66-100	351-570	2500-4000	721-1920
3	701-1800	401-1000	51-80	101-200	101-150	571-1400	4001-10000	1921-4630
4	>1800	>1000	>80	>200	>150	>1400	>10000	>4630

*Note: * TDCG exclude CO_2, it is not a flammable gas.*

The dissolved gas content that detected determines the initial failure of insulation failure (Table 2).

Table 2 The isolation failure in Key Gas Method [7]

Failure Types	Key Gas	Condition	Gas Content (%)
Arcing	Acetylene (C_2H_2)	High content of $H_2$and C_2H_2 Low content of CH_4 and C_2H_4 CO and CO_2 are possible if cellulose is involved	H_2 = 60% C_2H_2 = 30%
Corona	Hydrogen (H_2)	High content of H_2 Low content of CH_4, C_2H_6, and C_2H_4 CO and CO_2 are equal if cellulose is involved	H_2 = 85% CH_4 = 13%
Overheat of Oil	Ethylene (C_2H_4)	High content of C_2H_4 Low content of C_2H_6, CH_4, and H_2	C_2H_4 = 63% C_2H_6 = 20%
Overheat of Cellulose	Carbon monoxide (CO)	High content of CO and CO_2 Hydrocarbon may be present	CO: 92%

2.2 Breakdown Voltage

The value of breakdown voltage is the insulation ability of transformer oil to withstand the voltage given. If the value is high, the oil is still in good condition and cannot easily be penetrated by mains voltage.

2.3 Water Content

The insulation ability depends on the water content in transformer oil. Too much water content will reduce the insulating ability of oil [8]. The water content depends on the degradation of cellulose from the outside air.

3. RESULTS AND DISCUSSION

3.1 Failure Identification

Four samples of transformer oil were tested using Dissolved Gas Analysis. The results, which are shown in Tables 3, 4, 5, and 6, indicate the quality of each sample based on the Key Gas method.

Table 3 Result of DGA test for sample 1

Parameter	Hydrogen (H_2)	Methane (CH_4)	Ethane (C_2H_6)	Ethylene (C_2H_4)	Acetylene (C_2H_2)	Carbon monoxide (CO)	TDCG
Dissolved Gas Concentration (ppm)	27	10	22	0	0	49	108

Key Gas: Hydrogen (H_2) and Carbon monoxide (CO)

Failure indication: Corona and Overheat of Cellulose.

Table 4 Result of DGA test for sample 2

Parameter	Hydrogen (H_2)	Methane (CH_4)	Ethane (C_2H_6)	Ethylene (C_2H_4)	Acetylene (C_2H_2)	Carbon monoxide (CO)	TDCG
Dissolved Gas Concentration (ppm)	41	14	42	0	0	73	170

Key Gas: Hydrogen (H_2), Ethane (C_2H_6) and Carbon monoxide (CO)

Failure indication: Corona, Arcing and Overheat of Cellulose.

Table 5 Result of DGA test for sample 3

Parameter	Hydrogen (H_2)	Methane (CH_4)	Ethane (C_2H_6)	Ethylene (C_2H_4)	Acetylene (C_2H_2)	Carbon monoxide (CO)	TDCG
Dissolved Gas Concentration (ppm)	10	2	6	0	0	28	46

Key Gas: Hydrogen (H_2) and Carbon monoxide (CO)

Failure indication: Corona and Overheat of Cellulose.

Table 6 Result of DGA test for sample 4

Parameter	Hydrogen (H_2)	Methane (CH_4)	Ethane (C_2H_6)	Ethylene (C_2H_4)	Acetylene (C_2H_2)	Carbon monoxide (CO)	TDCG
Dissolved Gas Concentration (ppm)	67	2	12	0	0	45	126

Key Gas: Hydrogen (H_2) and Carbon monoxide (CO)

Failure indication: Corona and Overheat of Cellulose.

3.2 Correlation of Parameters

As the research objectives to keep the transformer oil performing optimally, a correlation test was carried out between its main parameters. Table 7 shows the value of Total Dissolved Combustible Gas, Breakdown Voltage, and Water Content of each sample.

Table 7 Main parameters of each sample

Sample	TDCG (ppm)	Breakdown Voltage (kV)	Water Content (mg/kg)
1	108	31	19
2	170	41	18
3	46	79	8
4	126	80	6

All parameters are calculated for the value of correlation that shows their relationship.

Table 8 Correlation Value of TDCG and Breakdown Voltage

Sample	TDCG	BDV	$x_i - \bar{x}$	$y_i - \bar{y}$	$(x_i - \bar{x})(y_i - \bar{y})$	$(x_i - \bar{x})^2$	$(y_i - \bar{y})^2$
1	108	31	-4.5	-26.75	120.375	20.25	715.5625
2	170	41	57.5	-16.75	-963.125	3.306.25	280.5625
3	46	79	-66.5	21.25	-1.413.125	4.422.25	451.5625
4	126	80	13.5	22.25	300.375	182.25	495.0625
Total					-1,955.5	7,931	1,942.75

$$\text{Corr}_{(x.y)} = \frac{-1{,}955.5}{\sqrt{(7{,}931 \text{ x } 1{,}942.75)}} = -0.4982$$

The coefficient of correlation between Total Dissolved Combustible Gas and Breakdown Voltage (Table 8) is -0.4982. It shows that TDCG and Breakdown Voltage have a weak inverse relationship.

Table 9 Correlation Value of TDCG and Water Content

Sample	TDCG	WC	$x_i - \bar{x}$	$y_i - \bar{y}$	$(x_i - \bar{x})(y_i - \bar{y})$	$(x_i - \bar{x})^2$	$(y_i - \bar{y})^2$
1	108	19	-4.5	6.25	-28.125	20.25	39.0625
2	170	18	57.5	5.25	301.875	3.306.25	27.5625
3	46	8	-66.5	-4.75	315.875	4.422.25	22.5625
4	126	6	13.5	-6.75	-91.125	182.25	45.5625
Total					498.5	7,931	134.75

$$\text{Corr}_{(x.y)} = \frac{-498.5}{\sqrt{(7{,}931 \text{ x } 134.75)}} = 0.4822$$

The coefficient of correlation between Total Dissolved Combustible Gas and Water Content (Table 9) is 0.4822. It shows that TDCG and Water Content have a weak direct relationship.

Table 10 Correlation Value of Breakdown Voltage and Water Content

Sample	BV	WC	$x_i - \bar{x}$	$y_i - \bar{y}$	$(x_i - \bar{x})(y_i - \bar{y})$	$(x_i - \bar{x})^2$	$(y_i - \bar{y})^2$
1	31	19	-26.75	6.25	-167.1875	715.5625	39.0625
2	41	18	-16.75	5.25	-87.9375	280.5625	27.5625
3	79	8	21.25	-4.75	-100.9375	451.5625	22.5625
4	80	6	22.25	-6.75	-150.1875	495.0625	45.5625
Total					-506.25	1.942.75	134.75

$$\text{Corr}_{(x.y)} = \frac{-506.25}{\sqrt{(1{,}942.75 \text{ x } 134.75)}} = -0.9894$$

The coefficient of correlation between Breakdown Voltage and Water Content (Table 10) is -0.9894. It shows that Breakdown Voltage and Water Content have a strong inverse relationship.

3.3 Regular Treatment

Transformer oil treatment is carried out based on three main parameters which indicate its performance. Oil testing is recommended to do regularly, particularly after 10 years. It is conducted to have the trend of the value of Total Dissolved Combustible Gas, Breakdown Voltage, and Water Content.

The Furan test (test for aromatic compounds) is recommended for oil performance testing after 15 years. It is conducted to determine the remaining lifetime of transformer oil. Refining the oil, which can improve the insulation ability, is also possible to extend its lifetime.

4. CONCLUSIONS

The transformer oil testing using Dissolved Gas Analysis indicates the failure at low energy levels because of the corona, arcing, and overheating of cellulose. The Total Dissolved Combustible Gas is not correlated with Breakdown Voltage or Water Content. However, the Breakdown Voltage and Water Content have a very strong inverse relationship, for example, the Breakdown Voltage of sample 1 is 31 KV with a Water Content of 19 mg/kg and Breakdown Voltage of sample 3 is 79 KV with a Water Content of 8 mg/kg.

The transformer oil testing is recommended every 3 to 6 months. The replacement time of the oil depends on the trend of each main parameter. The use of standard tools and the accuracy of the testing process are very important. If the value of Breakdown Voltage and Water Content is still normal, the transformer oil test is only on Dissolved Gas Analysis to indicate the failure earliest.

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