Analysis of Breakdown Voltage Test on Transformer Oil based on Dissolved Gas Analysis Test Result

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***Abstract*—Transformer which is in full-load operation and used continuously will create heating on the core, so that oil transformer is required not only as insulation but also as cooling medium. The impact of gases in oil insulation to breakdown voltage has been not investigated yet. This research implied an analysis about the impact of gases in insulation oil to breakdown voltage using multiple linear regression with 300 data. The analysis was conducted on each gas, all gases, three combinations of gasses, four combination gases without acetylene, and three combination gases without acetylene. The target of this research was to know the impact of gases in oil transformer to the value of breakdown voltage. The results showed that the gasses had impact of 0.325 on breakdown voltage classified as a slight impact for breakdown voltage.**

***Keywords—DGA, BDV, Transformer Oil, Double Linear Regression*.**

I. INTRODUCTION

Transformer utilize oil as its insulator and cooler. Transformer with large loads and continuous operation may experience heat on the core. Periodically increasing heat can lead to worsening of the oil which is dangerous and can cause breakdown or arcing. Heat helps the formation of gasses inside the oil, these gasses may indicate the quality of the oil. The test to determine gasses condition inside an oil is called dissolved gas analysis.

Experiment on how the gasses inside an oil affect the breakdown level had never been done before. Breakdown happen because particles such as dust, sand, and so on exist inside the oil. Breakdown is also affected by temperature, the higher the temperature is, the higher the breakdown voltage is [1]. Water content may as well have an effect to breakdown voltage. The more water inside the oil, the lower the breakdown voltage will be [2]. The previous experiment observed and analyzed breakdown voltage and DGA, as well as explaining about the oil reliability form each test without combining BDV and DGA test [3].

The experiment to find interrelation between gasses and oil breakdown uses statistic-based method, specifically double linear regression. Double linear regression can provide some values of the effect of gasses inside an oil as the results. It can also be used to find a function that will be helpful to determine what gas has the biggest effect on oil breakdown and to find the positive and negative effect caused by elements inside the oil. Experiment was done from collecting data, and then finding effective data value that matched the center of limit theorem [4]. After the effective method to check the data to obtain prove, methods stated before may be used to prevent data from bias. The test is called assumption tests which include 5 assumptions. If the assumptions are valued as true, the next step was finding the best regression among all data.

The goal of this experiment is to provide information about gasses effect on breakdown voltage using dissolved gas analysis that has never been done before. In this case, it need to be investigated that the gas elements contained in transformer oil have an effect or not on the level of probability of breakdown in oil and how the effect of the gas elements on transformer oil if statistical method is used.

II. THEORITICAL FRAMEWORK

Some research had been done in order to prove whether or not a DGA testing is necessary. For instance, the thermograph test that used breakdown testing results as the reference to be proven statistically in relation to the high temperature effect. The BDV, DGA, and Furan test done to calculate the health index according to IEEE are also in existence. The research used some data and a SPSS (Statistical Product and Service Solution) software that utilize Artificial Neural Networks on its method to find the correlation of a transformer health index according to the original transformer data [5]. However, research to prove whether or not the correlation between BDV test and DGA test exist had never been done before. The goal of this particular research is to find a comprehensive interrelation between soluble gas testing and voltage breakdown testing using double linear regression method with SPSS software.

A. Breakdown Voltage

Breakdown voltage on transformer oil could be caused by some factors, including the amount of water inside the oil, transformer thermal condition, and the existences of particles such as dust, sand, or others inside the oil. Transformer oil that had been used several times can lower its voltage breakdown level. Table I and II shows the criteria of transformer oil condition according to IEEE C57.106-2006 standard.

B. Dissolved Gas Analysis

DGA testing was done in order to find out what soluble gas elements existed inside the transformer oil, where the transformer oil itself might had other kinds of oil. By knowing the dissolved gasses, conclusion can be made according to IEEE regulation [6]. According to IEC 60599, gasses were classified into 4 condition as shown in Table III. Number 1 shows that the transformer is still in a normal condition. Number 2 and 3 shows possibilities of failure. Number 4 shows that if the transformer is still operating, failure will occur soon.

C. Double Linear Regression

Double linear regression was used to find out the effect of variables x (independent) on variables y (dependent). To use the double linear regression method, it is necessary to perform data check by using assumption test [7]. There are several types of assumption types, which are:

1) Normality Test

Normality test is a test conducted before applying linear regression analysis to find out the data contained in our analysis which does not have a remote monitored range, in which the data range that is owned must be identical, without having too much data uniformity.

2) Homoscedasticity Test

Homoscedasticity test is an assumption test treatment to see the existence of variable *x* to variable *y*, where this test is only fulfilled if *x* variable is spread without forming a certain pattern (to see in terms of scatter-plot) or can also use Park test, where Park test is used to testing homoschedacity using the LN value.

3) Reliability Test

Reliability test is a test to find out all variables have Cronbach alpha greater than alpha standard to find out this data can be justified. All variable values must have a calculated *r* value greater than *r* table with a 0.05 level of significance so that the output data seen later can be considered correct.

4) Autocorrelation Test

Autocorrelation test is a test that aims to determine whether or not there is a correlation between the x variable and the y variable as a whole. This test uses the classic assumption test based on Durbin-Watson. This test has 2 detections, namely: positive autocorrelation and negative autocorrelation.

5) Multi-colinearity Test

Multi-collinearity test is a test to determine the correlation between x variables or independent variables on the variable itself. So that multi-collinearity is not expected, because according to the name of the independent variable which means standing alone, each independent variable is required to have no attachments to each other.

6) Linearity Test

Linearity test is an important test to see whether the value of variable *x* to the value of the variable *y* is linear. This test is seen from the value of *F* table and *F* count.

Data form assumption test were expected to have normality result, no signs of homoscedasticity, must be reliable, have autocorrelation characteristic, no signs on multi-collinearity, and must be linear.

III. Double Linear Regression in Analysis of Gasses Effect on Oil Insulation

This section discusses the effect of gasses inside the oil on the breakdown voltage according to double linear regression method. For the analysis, the method used was comparison between gasses and breakdown level, using TDCG and Key Gases method. Flowchart for the method design is shown on Fig. 1.

A. Comparison Between Gasses and Breakdown

Gas comparison analysis compare the amount of gasses according to the condition described on Key Gases with the result of oil breakdown which could hold either of 2 outcomes, breakdown or no breakdown. Comparison was seen from each of the gasses and TDCG on certain conditions. That conditions were then compared in order to observe whether the scattering of the breakdown data had a threshold.

B. Key Gases

Key Gases method was used to determine failure on transformer according to dominant dissolved gas concentration. This method shows indications as shown in Table II.

TABLE I. Oil Breakdown Classification

Minimum Breakdown Voltage in kV	Voltage Class		
	≤69 kV	***69-230 kV***	***>230 kV***
1 mm	25	28	30
2 mm	40	47	50

TABLE II. Key Gases Failure Diagnostic

Failure Diagnostic on Transformer	Gas	Gas Amount (percent)
Arcing	Acetylene	H_2 = 60% C_2H_2 = 30%
Corona	Hydrogen	H_2 = 85% CH_4 = 13%
Excessive Oil Heating	Ethylene	C_2H_4 = 63% C_2H_6 = 20%
Excessive Sellulosa Heating	Carbon Monoxide	CO = 92%

TABLE III. TRANSFORMER CONDITION

No	H_2	CH_4	CO	CO_2	C_2H_4	C_2H_6	C_2H_2
1	≤100	≤120	≤350	≤2500	≤50	≤65	≤1
2	101-700	121-400	351-570	2501-4000	51-100	66-100	2-9
3	701-1800	401-1000	571-1400	4001-10000	101-200	101-150	10-35
4	>1800	>1000	>1400	>10000	>200	>150	>35

C. TDCG (Total Dissolved Combustile Gas)

TDCG analysis method was done to determine transformer oil condition in regard to the volume of formed gasses which are hydrogen, methane, carbon monoxide, carbon dioxide, ethylene, ethane, and acetylene. The conditions of TDCG could be seen in Table IV - VI. The result of TDCG indicate the transformer condition. Condition 1 would mean the transformer is in good working condition. Condition 2 would mean the transformer oil needs to be maintained periodically every three months. Condition 3 indicated that maintenance every month is needed. Condition 4 indicated a bad transformer oil, oil filtration is necessary.

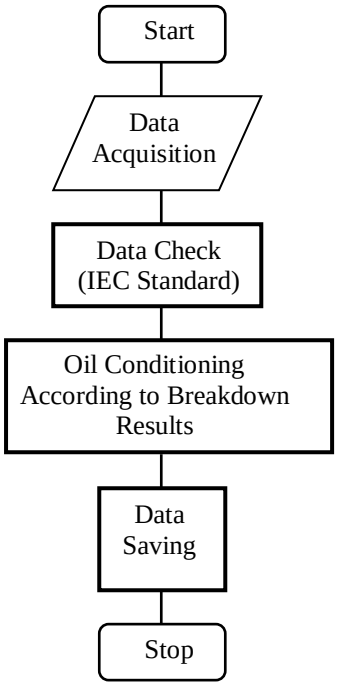

Fig. 1. Flowchat of used method

TABLE IV. TDCG CONDITION CLASSIFICATION

Condition Class	TDCG
Condition 1	<720 ppm
Condition 2	721-1920 ppm
Condition 3	1921-4630 ppm
Condition 4	>4630 ppm

TABLE V. EFFECT CORELATION CONDITION

Correlation Coefficient	Effect
0-0.2	Very Small
0.21-0.4	Small
0.41-0.6	Fair
0.61-0.8	Strong
0.81-1.0	Very Strong

TABLE VI. HETEROSCEDASTICITY ASSUMPTION TEST

Model	Sig.
Constant	0.215
Hydrogen	0.127
Methane	0.053
Carbon Monoxide	0.406
Carbon Dioxide	0.445
Ethyl	0.366
Ethane	0.452
Acetylene	0.102
Oxygen	0.251
Nitrogen	0.308

1) *Normality Assumption Test*

Result of this tests is true if all data including significant normal data > 0.05

2) *Heteroscedasticity Assumption Test*

This test is done in order to determine the data variants so that the acquired error can be reduced. The result is true if sig. is greater than 0.05.

D. Double Linear Regression

Double Linear Regression is a method used to find the effect of 2 variables, with varying number of variable x. Double Linear Regression is useful to determine the effect of gasses that existed inside an oil to its breakdown level. In the application of this method, assumptions are necessary, and the value of those assumption must be true so that the results of this method reflects the real condition.

1) *Multicolinearity Assumption Test*

This test aimed to determine the correlation between 2 variables, so it was expected that there are no multi-collinearity or relation between x variables. The test would make sure that all nine gasses are unrelated or have any relation, for example nitrogen would rise when oxygen rise, or acetylene reduced when hydrogen reduced. The method used for this assumption test is VIF or Variance Inflation Factor observation. VIF itself is a factor that reflects the rise of x variable. VIF values that were accepted must be lower than 10.

2) *Autocorrelation Assumption Test*

This test is done to time series data. Because the data used were collected over 2 years, this test can be done to determine time-related error. The results show that there was no sign of autocorrelation.

3) *Linearity Assumption Test*

Linearity test to make sure that the data have linear relation to each of the gas elements with BDV result on transformer oil. Test was done with significant value on each data, if the value is greater than 0.05 then linearity is true.

Assumption tests were done to fulfill the requirements of double linear regression. Double linear regression method could be used according to assumption test results. Form this method, the effect of each gasses to oil breakdown level were

visible, and so did the effect of all gasses, three gasses, four gasses without acetylene, and three gasses without acetylene. With all those being done, it was possible to determine which gas had the bigger potential on oil breakdown level. The result of this method matched what has been shown in Table V.

IV. Results and Analysis

The results data could be seen in Table VII - XII. Data of observed transformer condition were according to PT. PLN TJTBTB using 300 data that include breakdown, dissolved gas analysis, and water content data.

Using double linear regression method to obtain 3 output condition which were effect value as shown in Table V, function result, and output significant of gas elements that affect breakdown value. This experiment was simulated in SPSS with 300 transformer.

According to the SPSS simulation result, it was known that for each of the gas elements, the effect to the breakdown level were very small, matched the data shown in Table V.

On each of the gas elements' effect on breakdown, ethane gas had the biggest *R* (effect) value which was 0.117. Fig. 2 shows graphic result according to *R* value on breakdown.

Ethane was formed at 200-400 ^{o}C on oil transformer because of thermal faults. On gas comparison, each gas had very little correlation to breakdown. There was no pattern that shows how the gasses effect on breakdown matched with the gas condition analysis.

Methane was formed when the temperature reached 150-300 ºC, caused by corona, partial discharge, low and medium temperature thermal faults. Carbon monoxide was formed when the oil temperature reached 105-300 ºC. If decomposition and carbonization happen, it will form at 300 ºC. This gas was formed because thermal faults got affected by cellulose (paper isolation) form oil oxidation.

Carbon dioxide was formed along with carbon monoxide, caused by aging of oil transformer, thermal faults, and oil oxidation accumulation. Ethylene was formed when the oil temperature reached 300-700 ºC caused by particle discharge. Acetylene was formed when the temperature reached more than 700 ºC and may lead to arching. Meanwhile, oxygen was formed when temperature drop happened, caused by outside air entering the transformer, gas leak, and core leak.

During the experiment for all gasses, there was a *R* that had a value of 0.325 which was considered small correlation. Table IX shows the result of regression of all gasses to breakdown value, which is:

$$\text{Breakdown} = 0.024\ \text{Methane} - 0.002\ \text{Carbon Dioxide} - 0.016\ \text{Ethylene} + 0.008\ \text{Ethane} + 0.001\ \text{Oxygen} + 62.81$$

If the methane value rises by 1.993 ppm, the breakdown value of oil also increases by 33.998. Carbon dioxide gas has an effect of 3.223, so if the carbon dioxide value is reduced by 3.223 ppm, the breakdown value increases by 33.998. The breakdown value will increase by 33.998 if the ethylene value decreases by 2.256 ppm. The breakdown value increased by 22.998 if the ethane value increased by 1.942 ppm, or the oxygen value increased by 2.419 ppm.

The results of the simulation show that only methane gas, carbon dioxide, ethylene, ethane, and oxygen affect the oil breakdown value and even the influence value is small so that it proves that the gases formed in the oil have little effect on the breakdown. Methane is formed by temperatures at 150-300ºC which arise from low and medium thermal faults, and partial discharge. Carbon dioxide arises from temperatures reaching 105-300ºC due to the transformational age itself, and the effect of contamination from oil-insulating paper. Ethylene is formed at a temperature of 300-400ºC caused by high temperature thermal faults. Ethane is formed at a temperature of 200-400ºC due to low and medium thermal faults. Oxygen is formed due to the influence of outside air, there is a gas leak in the transformer oil.

During the observation of three gasses there was *R* that had a value of 0.255 which was considered small correlation. Table X shows the regression of all gasses to breakdown value, which is:

$$\text{Breakdown} = -0.002\ \text{Carbon Dioxide} + 0.008\ \text{Ethane} + 0.001\ \text{Oxygen} + 63.28$$

TABLE VII. Multi-colinearity Asummption Test

Model	Collinearity Statistics	
	Tolerance	***VIF***
(Constant)		
Hydrogen	0.961	1.041
Methane	0.333	3.003
Carbon Monoxide	0.566	1.766
Carbon Dioxide	0.672	1.489
Etylene	0.359	2.782
Ethane	0.547	1.828
Acetylene	0.945	1.058
Oxygen	0.822	1.217
Nitrogen	0.558	1.792

TABLE VIII. Correlation Value of Each Gasses to Breakdown

Gasses	Correlation Value
Hydrogen	0.078
Methane	0.085
Carbon Monoxide	0.018
Carbon Dioxide	0.038
Etylene	0.039
Ethane	0.117
Acetylene	0.107

Oxygen	0.106
Nitrogen	0.004

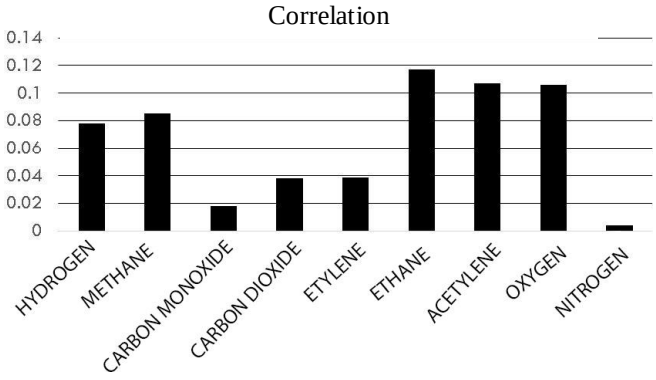

Fig. 2. Graph of all gasses effect on breakdown.

TABLE IX. RESULT OF ALL GASSES EFFECT ON BREAKDOWN

Model	R Value	R Value Square	Adjusted R Square
1	0.325[a]	0.105	0.078

TABLE X. RESULTS OF THREE GASSES EFFECT ON BREAKDOWN

Model	R Value	R Value Square	Adjusted R Square
1	0.255[a]	0.065	0.056

TABLE XI. RESULT OF 4 GASSES EFFECT ON BREAKDOWN

Model	R Value	R Value	Adjusted R Square
1	0.274[a]	0.075	0.062

TABLE XII. RESULT OF WATER CONTENT ON BREAKDOWN

Model	R Value	R Value Square	Adjusted R Square
1	0.769[a]	0.592	0.589

On the observation for 4 gasses without acetylene on breakdown there was R value of 0.274 which was considered to have low correlation value. Table XI shows the regression of all gasses on breakdown value, which was:

Breakdown= –0.031 Methane – 0.002 Carbon Dioxide – 0.017 Ethane + 0.001 Oxygen + 64.398

All method shows that all gasses had small effect on breakdown level. Gas concentration that exist inside transformer oil formed because of the oil activity, as stated in Key Gases. Therefore, since no experiment was done on the gas activity to prove that breakdown is affected by water, water content analysis was necessary and the results shows *R* value of 0.769 which considered as a strong correlation factor. The formula is: breakdown = -1.311 Water Content + 85.228.

V. CONCLUSIONS

Experiment results shows the effect of gasses inside transformer oil according to Dissolved Gas Analysis Test on oil breakdown voltage were fairly low. The effect of all gasses on breakdown voltage was at 32.5% with methane, carbon dioxide, ethylene, ethane, and oxygen had significant value on oil breakdown. Experiment results represented in the following formula:

Breakdown = 0.024 Methane – 0.002 Carbon Dioxide – 0.016 Ethylene + 0.008 Ethane + 0.001 Oxygen + 62.81

Looking at strings of three gasses, gasses with biggest effect was a combination of carbon dioxide, ethane, and oxygen with effect value of 25.5%. The formula was:

Breakdown= –0.002 Carbon Dioxide + 0.008 Ethane + 0.001 Oxygen + 63.28

On the 4 gasses combination, ethane, carbon dioxide, ethylene, and oxygen had an effect value of 27.4%. The formula was:

Breakdown= –0.031 Methane – 0.002 Carbon Dioxide – 0.017 Ethane + 0.001 Oxygen + 64.398

REFERENCES

[1] A. Junaidi, "Effect of temperature change to breakdown voltage on liquid insulation (In Indonesian)" *Penulisan Ilmiah, Fak. Teknol. Ind. Univ. Gunadarma*, vol. 13, pp. 1–5, 2008.

[2] A. Suherman *et al.*, "Effect of air contaminant (In Indonesian)" *Gravity*, vol. 2, no. 2, pp. 99–111, 2016.

[3] S. Kumpalavalee, T. Suwanasri, C. Suwanasri, and S. Wattanawongpitak, "Condition Evaluation of Power Transformers Using Dissolved Gas Analysis and Dielectric Breakdown Voltage Test."

[4] I. G. N. Agung, Statistics: Application of analysis method for perfect and unperfect tabulation with SPSS. *RajaGrafindo Persada*, 2003.

[5] A. C. M, D. A. Asfani, I. G. N. S. Hernanda, and K. Analisis, "Diagnosis of power transformer using transformer health indeks", vol. 1, no. 1, pp. 1–6, 2014.

[6] IEEE, "IEEE Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers." *IEEE*, Feb-2009.

[7] D. S. Pratomo and E. Z. Astuti, "Analysis of regresion and correlation between buyer and visitor to purchase nominal in Indomaret, Kedungmundu Semarang with Lowest Quadrant (In Indonesian)", Ilmu Komput., no. 1, 2014.