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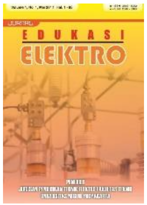

The Unit Auxiliary Transformer Analysis By Dissolve Gas Analysis and Breakdown Voltage Test

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Abstract The unit auxiliary transformer (UAT) is critical equipment at the Adipala steam power plant. Failure of this device can cause severe disruption to the generator, which can impact the Java-Bali electric power system. For this reason, the auxiliary transformer needs to be adequately maintained to ensure the equipment is in good condition. This article will discuss predictive maintenance efforts on UAT, including various inspections and tests on transformer oil to ensure the equipment can work properly. The research method includes carrying out various tests on the condition of transformer oil. The testing process involves taking samples of transformer oil, measuring the dissolved gas content, and testing the breakdown voltage in the laboratory. Data analysis using descriptive statistics referring to IEEE C57.104-2019 and IEC 60422-2013 standards. The test results showed that the oil condition increased the amount of dissolved gas beyond the permitted limit. Therefore, it is necessary to monitor oil conditions and temperature to ensure the UAT can work correctly.

Keywords: condition analysis, auxiliary transformers, UAT, DGA, BDV

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1 Introduction

Steam power plants are among Indonesia's most utilized. This plant utilizes the kinetic energy of a steam-driven turbine rotation. The turbine is coupled with a generator to produce electrical energy [1], [2]. Steam power plant is the main power generator that supports the electricity system in Indonesia. One of the critical components in a Steam power plant is the transformer. Team Power Plant requires an electrical power supply from the Auxiliary Transformer Unit (UAT). UAT is a step-down transformer that reduces the generator output voltage from 22 kV to 6.6 kV. This device functions to provide electricity supply in the Steam power plant environment. This UAT has a power capacity of 43 MVA with an ONAN/ONAF cooling system Kunlun Kelamayi oil type.

The UAT consists of several components, including a main tank, iron core, coil, on-load tap changer, bushing, oil, and so on [3], [4], [5]. Transformers operate by applying the principle of electromagnetic induction. The transformer operates continuously throughout the day and will stop when it enters the overhaul schedule. Electric current flowing through the coil causes heat, damaging the transformer's winding insulation [6]. [7], [8]. For this reason, the transformer windings need a cooling system. Most transformers use air and oil cooling to immerse the windings in the tank [9], [10]. Oil insulates and cools the transformer windings and core. The oil must have the ability to withstand breakdown voltage and reduce heat due to electric current. Failure of the oil to cool the

UAT and isolate the primary voltage can cause blackout problems. Therefore, so that the electric power system can run well and reliably, the condition of the transformer oil must be maintained from various kinds of disturbances [11], [12], [13].

UAT can experience failure in the form of thermal and electrical faults. Transformer failure is caused mainly by insulation failure [14], [15], [16]. Thermal stress affects transformer insulation. Insulating paper can decompose and react with transformer oil to form gas. Thermal stress in liquid insulation causes oxidation, which causes sludge and acid. Sludge can hinder heat transfer from the transformer coils. The acid content in transformer oil can reduce the dielectric strength of transformer oil [17], [18].

Meanwhile, mechanical stress is caused by short circuits. This event causes a large current to flow through the transformer coil. The transformer coil will experience interference when the insulation cannot withstand mechanical stress. Electrical stress in transformers has no significant impact except for partial discharge and arcing. Partial discharge and arcing are types of electrical stress that cause damage to transformer insulation [19], [20], [21].

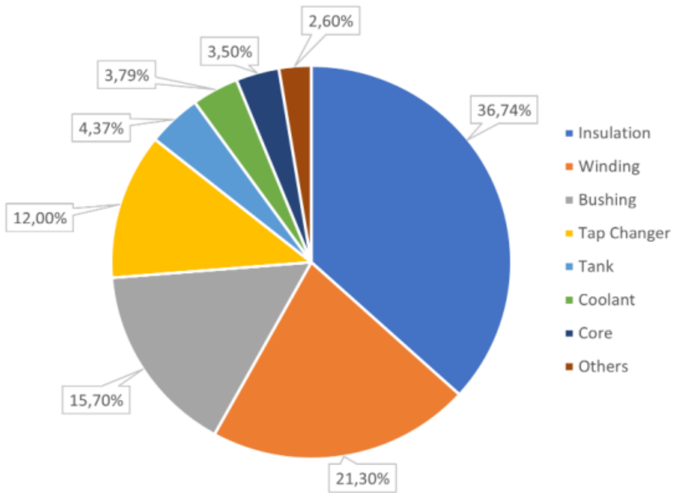

Fig. 1. Transformer fault statistics

Transformer oil is a mixture of hydrocarbon molecules containing CH_2, CH_3, and CH connected by chemical bonds. This bond can be broken due to electrical and thermal fault events [22], [23]. The decomposition of transformer oil can cause the formation of hydrogen gas (H_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), and acetylene (C_2H_2) [24], [25], [26]. The decomposition of transformer cellulose insulation causes the formation of carbon monoxide (CO) and carbon dioxide (CO_2) gas. In addition, transformer oil can contain dissolved gases caused by stray gassing events and catalytic reactions. These two events can occur even though the transformer is in typical condition.

Transformer insulation can experience a decrease in quality. Insulation conditions can be used to detect transformer health conditions. Dissolved gas analysis and breakdown voltage are oil tests to determine the condition of the transformer insulation [26], [27]. Dissolved gas analysis in transformer oil can analyze dissolved gas in transformer oil. Dissolved gas detected in DGA testing is called fault gas. Types of fault gas include H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, CO, and CO_2.

The heat generated due to overload and current disturbances can cause gas to form in the oil. Preventive and predictive maintenance requires checking and testing the condition of transformer oil to ensure that abnormal conditions do not occur. This article discusses checking and testing oil conditions in UAT using the DGA and BDV test methods. The results of the inspection and testing of transformer oil can provide information on whether the UAT can still operate. This information is beneficial for preventing UAT from experiencing work failures and predicting the economic life of the transformer.

2 Method

The DGA and Breakdown Voltage Test analyzed the transformer's condition. The research stages are as follows: 1) needs analysis by observing the condition of the transformer and discussing it with operators and technicians; 2) planning DGA testing and breakdown voltage tests. 3) sampling and testing transformer oil, 4) Analyzing test results by comparing them with IEC and SPLN standards, and 5) evaluating results and recommendations.

The data collection instrument uses a Myrkos Morgan Schaffer tool to detect, and measure dissolved gas concentration values in transformer oil samples. This tool uses a gas chromatography method, which requires a carrier gas and calibration. The detected dissolved gas concentration is expressed in ppm units. The second piece of equipment is the Megger OTS100AF to test the breakdown voltage. This tool measures the strength of transformer oil to withstand breakdown voltage.

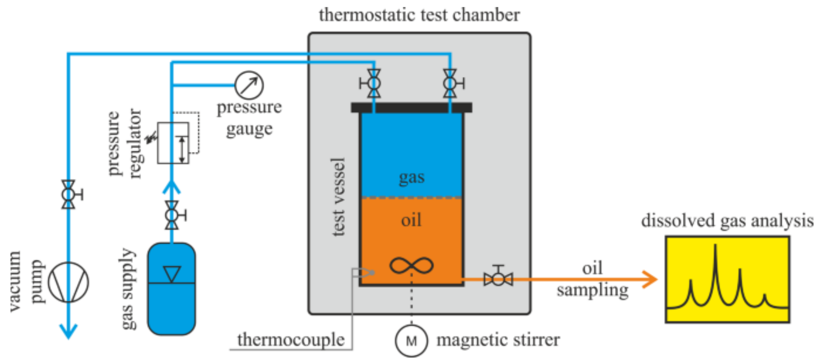

Fig. 2. Online dissolved gas analysis

Data analysis uses the Dissolved Gas Analysis method and Breakdown Voltage Test. The initial analysis calculated the delta value and dissolved gas rate. Delta is the difference in gas concentration values between the two most recent test data. Rate is the dissolved gas growth constant calculated using linear regression. Delta values and rate values are used for data interpretation. Data interpretation is used to determine the DGA status of transformer oil. DGA status is used to determine the following actions. The IEEE C57.104-2019 standard guides the DGA analysis. Fault identification is carried out to determine the type of failure in the transformer. The dissolved gas concentration value is used to predict the type of failure in the transformer. Fault identification uses the method listed in the IEEE C57.104-2019 standard. Breakdown voltage data analysis uses IEC 60422:2013 standard guidelines. This data analysis does not involve calculations but compares the data with standards. Data comparison produces a picture of the transformer oil condition. The results of this analysis can determine the suitability of transformer oil as an insulating material.

3 Result and Discussion

3.1. DGA Test Before Oil Purification

This research uses the UAT test results of the Steam power plant Adipala. UAT is a step-down transformer that reduces the generator output voltage from 22 kV to 6.6 kV. This transformer functions to provide electricity to the Steam power plant environment. This transformer has a power capacity of 43 MVA with an ONAN/ONAF cooling system. UAT uses Kunlun Kelamayi DB25 oil type. Transformer failure causes the formation of fault gas in the oil. UAT experienced abnormal conditions in October 2022. Dissolved gas analysis test results showed that the value of H_2 in the UAT oil exceeded standard limits. The H_2, CO, and CO_2 also exceed standard limits. Therefore, an analytical test was carried out on the transformer oil to determine its condition.

Table 1. DGA test before oil purification

Device ID	Unit Auxiliary Transformer				Delta (ppm)	Rate (ppm/year)	Limit Standard IEEE			
Sampling	Data 1	Data 2	Data 3	Data 4			Tabel 1	Tabel 2	Tabel 3	Tabel 4
Days -	0	42	153	234						
Parameter	Result (ppm)									
Hydrogen (H_2)	21	29	73	63	8	23,5	40	90	25	10
Methan (CH_4)	0	0	0	0	1	3,36	20	60	10	3
Etana (C_2H_6)	0	0	0	0	0	0	15	40	7	2
Ethylene (C_2H_4)	0	0	0	0	0	0	60	125	20	5
Acetylene (C_2H_4)	0	0	0	0	0	0	2	7	Any increase	
Carbon Monox-ide (CO)	82	104	244	256	32	186,65	500	600	175	80
Carbon Dioxide (CO_2)	1402	1529	2206	2667	292	944,91	5500	8000	1750	800
Methan (CH_4)	12189	11556	13320	12792						
Nitrogen (N_2)	31234	30982	37417	47876						
CO_2/CO	17,19	14,70	7,82	10,21						
O_2/N_2	0,38	0,38	0,27	0,3						

The results of the DGA data interpretation show that fault gas concentration values exceed normal limits. The measured concentration value of H_2 was 63 ppm. The provisions of Table 1 in IEEE C57.104-2019 state that the limit value for H_2 concentration is 40 ppm. On the other hand, the concentration value of all fault gas is below the limit. The delta value for all gas faults is included in the normal category because it is below the limit. The rate values for some gas faults exceed normal limits. The H_2, CH_4, CO, and CO_2 exceed the limits. The concentration of ethane, ethylene, and acetylene gas is 0 ppm. This condition indicates no ethane, ethylene, and acetylene gas formation in the transformer oil.

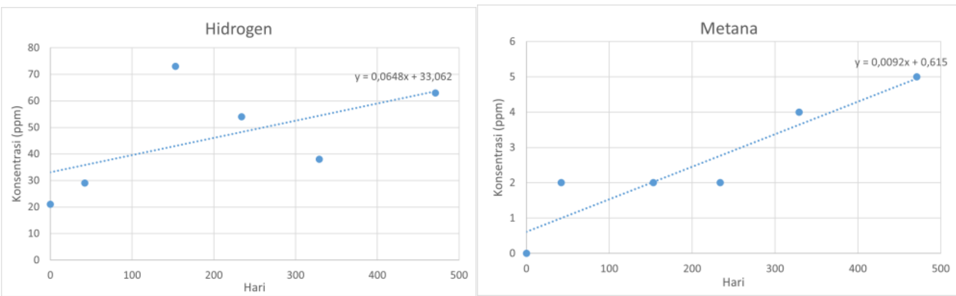

Fig. 3. Graph of hydrogen and methane gas before oil purification

The transformer gas growth graph determines dissolved gas activity in transformer oil. The transformer has a constant load of 27.13 MW. The transformer loading percentage is 78%. The transformer oil temperature is below 50ºC when the transformer is operating. The regression coefficient (b) is optimistic based on linear regression calculations. This value means that every day (X) increases, the fault gas concentration value (Y) in the transformer oil increases. This condition can be proven in the graphs of hydrogen, methane, carbon monoxide and carbon dioxide gases. The graphs for the four gases tend to increase. Therefore, there is an increase in the production of hydrogen, methane, carbon monoxide and carbon dioxide gases in transformer oil.

3.2. DGA Test After Oil Purification

Based on the results of the DGA test after purification, the fault gas concentration value in the transformer oil has decreased significantly. All fault gas concentration values are below the standard limits of Table 1, written in IEEE C57.104-2019. The test result data after purification becomes the initial DGA test sample for auxiliary transformer B unit oil. The initial sample is the initial data used as an initial benchmark for the results of subsequent dissolved gas analysis tests. The delta and rate values cannot be determined because the initial samples are the first data, so there is no comparative data yet.

Table 2. DGA test after oil purification

Device ID	**The UAT**				**Delta (ppm)**	**Rate (ppm/year)**	**Limit Standard IEEE**			
Sampling	Data 1						Table 1	Table 2	Table 3	Table 4
Days	0									
Parameter										
Hydrogen (H2)	0				8	23,5	40	90	25	10
Methan (CH_4)	0				1	3,36	20	60	10	3
Etana (C_2H_6)	0				0	0	15	40	7	2
Ethylene (C_2H_4)	0				0	0	60	125	20	5
Acetylene (C_2H_4)	0				0	0	2	7	Any increase	
Carbon Mon-oxide (CO)	8				32	186,65	500	600	175	80
Carbon Dioxide CO_2)	151				292	944,91	5500	8000	1750	800
Metana (CH_4)	128 91									
Nitrogen (N_2)	45791									
CO2/CO	18,88									
O_2/N_2	0,28									

3.3. Identify Auxiliary Transformer Unit Failure

Failure identification is a method for discovering failures in the transformer. Transformer failure becomes the basis for evaluating and determining action against the transformer. There are 6 methods for identifying transformer failure, including the Roger ratio, essential gas, Doernenburg ratio, Duval Pentagon 1, Duval triangle, and Duval Pentagon 2. In addition, CO and CO_2 are identified as indicators of cellulosic insulation failure in transformers. Identify transformer failure using dissolved gas analysis test results.

Table 3. DGA test results before oil purification

No	**Fault Gas Type**	**Concentration (ppm)**
1	Hydrogen (H_2)	63
2	Methan (CH_4)	5
3	Etana (C_2H_2)	0
4	Ethylene (C2H4)	0
5	Acetylene	0
6	Carbon monoxide	336
7	Carbon Dioxide	2667

UAT occupies DGA 3 status, so fault identification is carried out to determine the failure that occurred. The critical gas method cannot identify transformer failure because only hydrogen and a small amount of methane exist. There are no traces of the formation of ethylene and ethane gas. The Roger ratio and Do-Ernenburg ratio identification methods cannot be applied to identify the failure of the auxiliary transformer B unit. These two methods require ethane, ethylene, and acetylene gas concentration values to calculate the gas ratio value. The failure in UAT also cannot be described using the Duval triangle and Duval Pentagon. The depiction of these two methods requires ethane, ethylene, and acetylene gases as reference points. Based on the Interpretation of CO and CO_2, the gas formed is normal gassing.

3.4. Breakdown Voltage Test Results Before Oil Purification

Table 4. BDV test results before purification

Date Sampling		November 20th, 2022,		
Device ID		Trafo		
Gap		2,5 mm		
Device Category		C		
Test	**Breakdown Voltage (kV)**	**Limit (IEC 60422-2013)**		
		Good	***Fair***	***Poor***
Test 1	87,4	>40 kV	30-40 kV	<30 kV
Test 2	81,5			
Test 3	80,2			
Test 4	74,1			
Test 5	97,6			
Test 6	98,7			
Rata-rata	86,6			

From the six tests, the average value is taken to determine the condition of the transformer oil. Based on Table 6, the average breakdown voltage for UAT oil is 86.6 kV with a distance between electrodes of 2.5 mm. According to IEC 60422-2013, the standard breakdown voltage value is >40 kV with an electrode distance of 2.5 mm. Thus, the breakdown voltage test results for the auxiliary transformer B unit are included in the excellent category.

3.5. Breakdown Voltage Test Results After Oil Purification

Transformer oil testing uses the breakdown voltage method, which is carried out twice after purification. The first oil sample is taken when the transformer is in offload condition. The second oil sample was taken when the transformer was in an on-load condition.

Table 5. BDV test results after offload purification

Date Sampling		December 29th, 2022,		
Device ID		Unit Trafo		
Gap		2,5 mm		
Device Category		C		
Test	**Breakdown Voltage (kV)**	**Limit (IEC 60422-2013)**		
		Good	***Fair***	***Poor***
Test 1	88,4	>40 kV	30-40 kV	<30 kV
Test 2	99,9			
Test 3	100,2			
Test 4	91,5			
Test 5	59,7			
Test 6	82,2			
Rata-rata	87,0			

Breakdown voltage testing after purification, when the transformer is in offload condition, is used to determine the suitability of the purification results. Through this test, it can be seen whether the purification results are following the specified standards. If it is suitable, the transformer oil can be used again.

Table 6. BDV Test Results After Onload Purification

Date Sampling		December 29th, 2022,		
Device ID		Unit Auxiliary Transformer		
Gap		2,5 mm		
Device Category		C		
Test	Breakdown Voltage (kV)	Limit (IEC 60422-2013)		
		Good	*Fair*	*Poor*
Test 1	94,6	>40 kV	30-40 kV	<30 kV
Test 2	83,5			
Test 3	54,4			
Test 4	82,7			
Test 5	79,2			
Test 6	78,3			
Average	78,8			

The UAT is included in equipment category C. According to IEC 60422-2013, the standard breakdown voltage value is >40 kV with a distance between electrodes of 2.5 mm. Based on Table 7, the average value of transformer oil breakdown voltage is 87 kV with a distance between electrodes of 2.5 mm. This data shows that the results of transformer oil purification are following standards. Based on Table 8, the average value of UAT oil breakdown voltage is 78.8 kV. There is a decrease in the breakdown voltage value when the transformer is in an on-load condition. The results of the two breakdown voltage tests show that the average breakdown voltage value exceeds the standard limit. Thus, the breakdown voltage test results are included in the excellent category.

3.6. Discussion

Before the oil purification process, the DGA status of the auxiliary transformer unit B was in DGA status 3. This condition was caused by the concentration value of H_2 and the rate value of several fault gases such as H_2, CH_4, CO, and CO_2 exceeding the IEEE C57.104-2019 standard limit. A transformer with DGA status 3 is considered suspicious because there is an increase in dissolved gas in the oil. There are indications of partial discharge failure in the auxiliary transformer B unit because the hydrogen gas concentration exceeds the standard Table 1. Based on IEEE C57.104-2019, the formation of hydrogen gas is caused by partial discharge events. However, this has not been confirmed to be true. There is a need for fault identification to determine the type of failure based on the dissolved gas analysis test results.

The UAT undergoes a purification process. The results of inspections and tests are the basis for whether transformer oil needs to be purified or replaced. After purification, the oil's dissolved gas concentration value decreased drastically. Oil transformer purification can reduce transformer oil contamination of sediment, water content, and dissolved gas. The decrease in the dissolved gas concentration value is only temporary. The dissolved gas concentration value will increase when the transformer operates and experiences failure. It is recommended that a dissolved gas analysis test be carried out every three months to monitor the growth of dissolved gas in oil.

Before purification, the UAT unit is in DGA 3 status, so fault identification is carried out to determine the type of transformer failure. Based on IEEE C57.104-2019, several fault identification methods, including essential gas, Roger ratio, Doernenburg ratio, Duval triangle, Duval pentagon 1, and Duval pentagon 2. In addition, CO and CO_2 were identified to determine the involvement of cellulose insulation in failure. The fault identification results on the auxiliary transformer B unit did not indicate a failure. Dissolved Gases formed in the oil are not caused by transformer failure. The gas in transformer oil is a typical gas that can form when the transformer operates.

Hydrogen gas (H_2) in transformer oil is not caused by partial discharge failure. Other factors cause the formation of hydrogen gas (H_2). Based on CIGRE (2019), transformers' catalytic reactions can produce large amounts of hydrogen gas (H_2). This reaction can occur when the transformer temperature is under normal conditions. Based on IEEE C57.104-2019, the decomposition of cellulose insulation can produce CO and H_2) gas. This event can occur even though the transformer is in typical condition. The transformer operating temperature influences the gas growth rate. Based on this, it can be concluded that H_2 in UAT oil is formed due to catalytic reactions and the decomposition of cellulose insulation.

UAT breakdown voltage testing before purification occurs when the transformer is under load. The average value of the breakdown voltage measured was 86.6 kV. The breakdown voltage standard is based on IEC:60422-2013, namely 40 kV. The breakdown voltage value of oil exceeds the standard limit. This data shows that the transformer oil is in good condition and can withstand breakdown voltage. Breakdown voltage testing after purification was carried out twice. The first test is carried out when the transformer is not under load. The test results show that the transformer breakdown voltage value is 87.0 kV. The second test is carried out when the transformer is under load. The test results show a breakdown voltage value of 78.8 kV. Transformer loading can affect the breakdown voltage value. The greater the transformer loading value, the smaller the breakdown voltage value. Therefore, there is a decrease in the value of the oil breakdown voltage when the transformer is not under load and load.

Transformer oil purification can increase the breakdown voltage value. Oil purification can improve the breakdown voltage value of transformer oil. The breakdown voltage value of oil increased after transformer purification. The increase in the breakdown voltage value is only temporary. The breakdown voltage value will continue to decrease when the transformer is operating. Transformer oil can only maintain a maximum breakdown voltage one year after purification. Therefore, it is necessary to purify again to prevent damage to the transformer and clean contaminants in the oil.

4 Conclusion

The results of the analysis of the condition of UAT based on the Dissolved Gas Analysis test show that the transformer oil is in DGA 3 status. There was no failure in UAT, only increased dissolved gas production. Hydrogen gas in transformer oil is formed due to catalytic reactions and the decomposition of cellulose insulation. Both things can happen even though the transformer is in typical condition. Based on the Breakdown Voltage Test, oil in the UAT is in good condition and suitable for use as insulation. It is recommended that UAT oil be tested every three months and purified once a year. This recommendation is made to prevent damage to the transformer oil.

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