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Analysis of Oil Dielectric Strength Insulation on Oil Circuit Breakers Based on Service Life and Operating Frequency

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ABSTRACT

The electricity distribution breakdown can be caused the service life and operating frequency of Oil Dielectric Strength (ODS). Hence, it requires a study due to the spare part is difficult to find. This paper aims to test the ODS on Oil Circuit Breaker (OCB) of 13.8 kV aged between 29 to 43 years. The test used the ASTM D1816 standard to analyze the effect of oil life and circuit breaker operating frequency on the physical, color and strength of ODS. For the visual test used the ASTM D1524 standard. The color test was based on the ASTM D1500 standard. From the test results found the 6DN F1 was yellow-black in colors. The color level was from 0.5 to 6, which was a striking color difference. This happens because it had been operating for 3 years with a frequency of 2 manual open times and 11 trips with a large normal load of 206A. In the 8D F7 feeder, there was also a decrease in breakdown voltage, which was far from 45.6 kV to 9.7 kV. Therefore, the oil was declared failed due to below the minimum standard of 27 kV. Based the validity test, the six samples were still within the allowable limits based on ASTM D1816 with the range value being below 92%. This means that the six samples were valid.

KEYWORDS: *Oil Circuit Breaker, Oil Dielectric Strength, Operating Frequency, Validity Test*

NOMENCLATURE

$\bar{V}$	*Average voltage (kV)*
n	*Number of tests*
Vn	*Rated breakdown voltage (kV)*
Vh	*Highest breakdown voltage (kV)*
Vl	*Lowest breakdown voltage (kV)*
V range	*Distance between highest and lowest voltage (kV)*

1.0 INTRODUCTION

The electrical power system engineering has designed to be able to quickly disconnect and isolate the fault area [1]–[3]. So, the disturbance does not have a direct impact on the system. Hence, the stability and reliability of the system are maintained [4]. To maintain system stability and reliability is an important part of protection [3], [5]–[7]. The protection system must meet the requirements of speed and automatically disconnect the disturbed part of the power grid, and minimize the interruption of electricity supply to consumers [4] [8]. The ability to disconnect that is a disturbance in the power system must exist in the protection system, namely the circuit breaker [6] [9]. The circuit breakers are also known as switches that operate automatically, which function when a fault is detected by interrupting the flow of current. Besides being used during fault conditions, the circuit breaker is also used under normal conditions to cut off the flow of electric current in the system during maintenance [10] [11]. There are many types of circuit breaker sizes, ranging from small to large scale. Switchgear is used for protection of low-current systems to high-voltage networks, such as MCCB (Mold Case Circuit Breaker), MCB (Miniature Circuit Breaker), ACB (Air Circuit Breaker), OCB (Oil Circuit Breaker), VCB (Vacuum Circuit Breaker), SF6CB (Sulfur Circuit Breaker [3], [4], [7], [8], [10]–[14].

Oil Circuit Breaker OCB type circuit breaker is widely used in transmission and distribution systems [15]. OCB that use oil as insulation for electric spark jumpers are called Bulk Oil Circuit Breakers (BOCB)[14] [15]. This type is equipped with an electric arc limiter. OCB failure resulting in fire or explosion is rare. However, it is possible that a fire in mineral oil may occur due to the breakdown of the insulating liquid inside the equipment (caused by switching, lightning surge, or by gradual breakdown), low insulating oil level, moisture instruction in the insulating oil, or by insulation failure. One of the most important factors to consider in OCB is the insulating strength of the oil against operating voltage. Failure can also occur influenced by the service life and operating frequency of the OCB.

The insulating oil in the OCB functions as insulation between the live parts and the body as a coolant in the event of an arc. The insulating strength of this oil must be considered so that it is always within safe limits to withstand operating voltages and disturbances, not to reach the breaking point.

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When the dielectric strength of this oil reaches the breakdown point, it will cause a short circuit from the live part to the inner ground (OCB body) [15]. As a result, there will be many losses [16], such as damage to the OCB that burns due to failure of oil insulation, disturbance to the system, the load can die, and consumers lose power supply . This oil insulation failure can be overcome by carrying out maintenance and paying attention to the problem of dielectric strength/Oil Dielectric Strength (ODS) so that it is not below the minimum permitted standard. By means of physical inspection, operating frequency, oil insulation testing periodically.

In this research, oil dielectric test (ODS) will be carried out on OCB 13.8 kV at PT. CPI age ranged from 29 to 43 years. Because spare parts are difficult to find, they require more attention to avoid serious damage, which causes a lot of damage to spare parts, losses for customers, and maintains the availability and reliability of operations. Testing using the ASTM D1816 standard is the Standard Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using VDE Electrodes [17] which will analyze how the effect of oil life and circuit breaker operating frequency on the physical, color and dielectric strength of the oil (ODS). For the visual test using the ASTM D1524 standard [18], and the color test based on the ASTM D1500 standard [19] [20].

2.0 METHODOLOGY

In this research, a test was conducted to examine the relationship between the number of operating frequencies and the age of the oil with Oil Dielectric Strength (ODS) kV using the ASTM D1816 standard [19]–[21]. The case study was held at the Power Generation and Transmission (PGT) electrical substation of PT. CPI aged between 29-43 years. The study was carried out to obtain the breakdown voltage value for the 13.8 kV OCB oil liquid insulation. Insulating oil testing used Nynas manufactured mineral type, Nytro Libra type, which is manufactured in compliance with IEC 60296 edition 5.0 [22] insulating oil, standard classification grade A.

Other test was carried out the visual test referring to the ASTM D1524 standard [18], the ASTM D1500 standard color test [19][20] with a color scale can be seen in Figure 1.

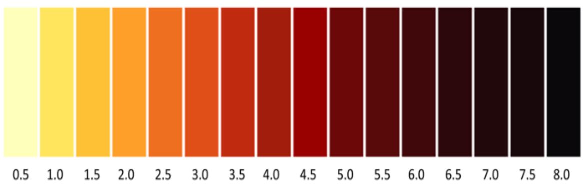
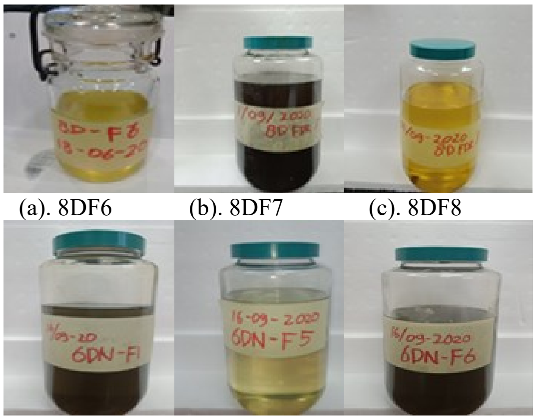


Figure 1: Demonstrative ASTM D1500 color scale [20]

Insulating oil samples were taken according to the IEEE Guide for Acceptance and Maintenance of Insulating Oil in Equipment. To minimize errors in sampling, the procedure refers to the standard ASTM D923 [23] or ASTM D3613 [24]. There were 6 samples taken, which can be seen in Figure 2. The Merger OTS60SX2 semi-automatic high-voltage tester was used to test the dielectric strength of liquid insulating oils.



(a). 8DF6 (b). 8DF7 (c). 8DF8

(d). 6DNF1 (e). 6DNF5 (c). 6DNF6

Figure 2: Insulating oil sample data of OCB 13.8 kV

Tests were carried out on specifications for output voltage 0-60 kV, test frequency 61.8 Hz, Transformer rating 500VA, Output disconnection within 1 millimeter/second after a breakdown had been detected, power supply 115/230 v with selector switch ((99-132 V), 198- 264 V), 50/60 Hz, max 80 VA. Furthermore, semi-automatic operation with selector switch for voltage increase of 500/2000/3000 Volt/second, pause function with 1 minute self-timer, operating temperature and humidity range: 0-40 (32-104), 80%R H at 40 (104), dimensions LxWxH = 401x260x380 mm, weight 17 kg.

Test based on ASTM D1816 Standard, with standard electrode ball VDE 0370, ball spacing of 2 mm. Room temperatures was conducted to testing 20-30. Test of the voltage in increments of 500 V/s, frequency 45-65 Hz. The test voltage is broken if it is <100 V. Next, 1 sample is tested 5 times; the time interval between tests is 1-1.5 minutes. The time interval between pouring the sample and starting the test was 3-5 minutes. The cover was used when testing, so that outside air did not enter the test vessel. The minimum breakdown voltage for new oil was 35 kV and used oil of 27 kV [17].

The sample taken was tested, which the test object was subjected to a voltage that was continuously increased by 0.5 kV/s until the test object breaks through electricity. This test was repeated 5 times to obtain 5 values of the breakdown voltage of the test object. To determine the average voltage of the test breakdown voltage, the formula in equation 1 is employed [17].

$$\bar{V} = \frac{1}{n}\sum_{1}^{n} V_n \qquad (1)$$

Determine the breakdown voltage range of 5 times the test, using equation 2 [17]:

$$Vrange = Vh - Vl \qquad (2)$$

Equation 3 was used to determine the validity test [17]:

$$Validity\ test = \left(\frac{Vrange}{\bar{V}}\right) * 100\% \qquad (3)$$

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According to the ASTM D1816 standard, for a ball spacing of 2 mm, the range must be less than 92% of the average rated breakdown voltage of 5 times. The calculation of this range was to determine the validity of the test results. If this range exceeds the 92% value limit, the test must be repeated with a new sample of oil. This method was used in high-voltage AC testing.

3.0 RESULT AND DISCUSSION

Samples of 13.8 kV OCB insulating oil were taken according to the recommendations of the ASTM D923 standard [23], to facilitate the identification and analysis of test data. The data taken were the location of the substation, the name of the feeder, the date of sampling, the temperature at collection time, the serial number, the year of production of OCB, the maximum operating voltage of CB, the current carrying capacity (KHA), the load current, and the previous year of service. The 13.8 kV OCB sample data is shown in Table 1.

Table 1: Operating life data of OCB 13.8 kV

No.	Feeder Name	OCB Serial Number	Production Year	Operating Voltage (kV)	KHA *CB* (A)	Load Current (A)	Temperature Sampling (°C)	Previous Year of Service	Data Retrieval Date
1	8D F6	40425-1	May-81	14.4	1200	234	30	11/28/2016	6/18/2020
2	8D F7	43725-2	Jan-89	14.4	1200	248	30	9/13/2017	9/2/2020
3	8D F8	39822-1	May-79	14.4	600	189	30	9/26/2017	9/2/2020
4	6DN F1	47578-3	Sep-93	14.4	1200	206	28	9/7/2017	9/16/2020
5	6DN F5	47578-4	Sep-93	14.4	1200	60	28	8/12/2019	9/16/2020
6	6DN F6	47578-2	Sep-93	14.4	1200	198	28	8/30/2019	9/16/2020

From the data in table 1, it can be seen that the operating life from the year of production, the last service time to sampling. Another important data was needed in this research of the OCB operating frequency data of 13.8 kV that was obtained from accessing the SCADA portal PGT (Power Generation & Transmission). In Table 2, the manual and trip data of 13.8 kV OCB from 2016 to 2020 were recorded according to research needs. This manual operation data was the operation of the breaker operated by the operator was turned off/opened directly. The trip data was the operating data of breaker operated by tripping by a disturbance in the network, which can be seen in Table 2.

Table 2: The disturbance network data of OCB 13.8 kV

Year	Data Trip *OCB* 13,8 kV											
	8F 6		8F 7		8F 8		6DN1		6DN5		6DN6	
	Manual	Trip	Manual	Trip	Manual	Trip	Manual	Trip	Manual	Trip	Manual	Trip
2016												
2017		5		1			1					
2018		0	2	1				1				
2019		1		1				9	1			
2020		2	1				1	1	1		1	4
	0	8	3	3	0	0	2	11	2	0	1	4
TOTAL	8		6		0		13		2		5	

3.1 Visual Testing of the OCB 13.8 kV

Visual testing of 13.8 kV OCB, the sample taken would be subjected to visual testing based on the ASTM D 1524 standard [18]. Visual test results and color of 13.8 kV OCB Insulating Oil can be seen in Table 3.

Table 3: The OCB insulating oil color and visual test results of 13.8 kV

No.	Feeder	Oil Life (year)	Frequency OCB Operation (Times) Manually	Frequency OCB Operation (Times) Trip	Initial Color Level Before Operation	Initial Color Level After Operation	Color	Contamination	Description
1	8D F6	4	0	8	0.5	1.5	Yellow	H2O and carbon	Bad
2	8D F7	3	3	3	0.5	7	black	carbon	Bad
3	8D F8	3	0	0	0.5	1.5	Yellow	clean	Good
4	6DN F1	3	2	11	0.5	6	Dark Yellow	carbon	Bad
5	6DN F5	1	2	0	0.5	0.5	Light Yellow	clean	Good
6	6DN F6	1	1	4	0.5	6	Dark Yellow	carbon	Bad

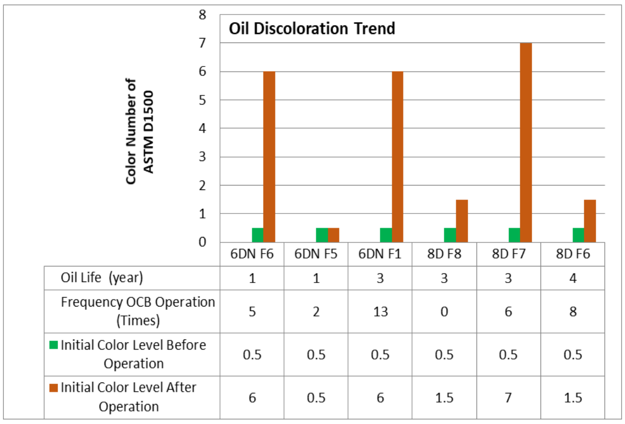

Figure 3: Graphics of visual and color physical test results for the OCB Insulating Oil 13.8 kV

From Figure 3, it is clear that there is a change in color due to the influence of the number of operating frequencies and the life of the oil. The explanation starts with the order of the small scale values, then the large ones. In the 6DN F5 sample, it is clear yellow, the color n small, still within 1 color scale of 0.5. Because, it is only 1 year of operation and the number of operating frequencies of 2 times manual open operation, with a normal load of only 60 A. There are no water or carbon contaminants in it. For sample testing of 8D F8, it is clear yellow, the color changes from 0.5 to 1.5, there is a slight change even though, it has never been in operation. This is due to the age factor, namely 3 years of operation, with a large normal load current of 189 A. There were no water contaminants or substances carbon in this test result.

The 8D F6 feeder has a cloudy yellow color, the color changes from 0.5 to 1.5, with an operating frequency of 8 trips and a service life of 4 years. The normal load current is 234 A. In the sample, there is no visible presence of carbon because the sampling was carried out after the OCB opened, and the carbon had precipitated. The sample of water contaminants are white grains. The sample 6DN F6 is yellow-black in color, the color level is from 0.5 to 6. There is a striking color difference even though the operating life of 1 year of operation. Because

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the operating frequency is quite a lot, 1 manual open and 4 trips, the normal load is large 198 A. There was a lot of carbon contamination in the oil.

For the 6DN F1 sample, the color is yellow-black, and the color level is from 0.5 to 6. There is a striking color difference, because, it has been operating for 3 years with a frequency of 2 manual open and 11 trips with a large normal load of 206A. There were many carbon contaminants in the oil.

For the black 8D F7 sample, the color level is from 0.5 to 7. There is a striking color difference, because, it has been operating for 3 years with a frequency of 3 manual open and 3 trips. At normal load, the current is 248 A so there is a big influence on the color change of the oil, when it operated manually. There were many carbon contaminants in the oil. Based on the analysis of the six samples, this color change was more dominantly sharp due to the large number of operating frequencies rather than the service life of the oil. The impact of the many operating frequencies was the occurrence of carbonization due to the chemical reaction between the arc and the oil.

3.2 OCB Electrical Test Results Data 13.8 kV

Samples that have been taken and physical tests were carried out, and then electrical tests were carried out. This electrical test was carried out at the PGT Minas Shop in a room with a room temperature of 24, the test date was in accordance with the date of collection and an electrical test was carried out. This electrical test for 13.8 kV OCB insulating oil was a test to get the value of the dielectric resistance of the oil in holding the test voltage until a breakdown voltage occurs in kV units. Dielectric strength test data can be seen in Table 4.

Table 4: Dielectric strength test data (ODS) OCB insulating oil of 13.8 kV

No.	Feeder	Breakdown Voltage 1 (kV)	Breakdown Voltage 2 (kV)	Breakdown Voltage 3 (kV)	Breakdown Voltage 4 (kV)	Breakdown Voltage 5 (kV)
1	8D F6	5.90	4.30	4.80	4.00	5.10
2	8D F7	10.9	11.5	9.8	8.2	8.1
3	8D F8	26.8	29.6	28.5	32.1	34.2
4	6DN F1	20	18.9	18.3	19.5	20.6
5	6DN F5	29.7	29.6	30	34	29
6	6DN F6	33.1	32.6	35.3	32.7	29.9

The test results can be seen in Table 4 and Figure 4. The values for each test were starting from tests 1 to 5 in each sample. In 5 times of testing, it produces different values of the breakdown and acronyms. From the calculation results in Table 5, it can be seen that the range of six samples was still within the allowable limits based on ASTM D1816. The six samples have the range value below 92%. It means that these six samples were valid. The average value of breakdown voltage represents the value of dielectric strength of oil in each sample. There was no need to take a new sample for retesting. The results of the insulating oil test, the data obtained can be seen in Table 6. From the data on results of the oil dielectric test in table 4, the average value was calculated. This average value was considered as data that represents the dielectric strength of oil from the sample taken from 13.8 kV OCB.

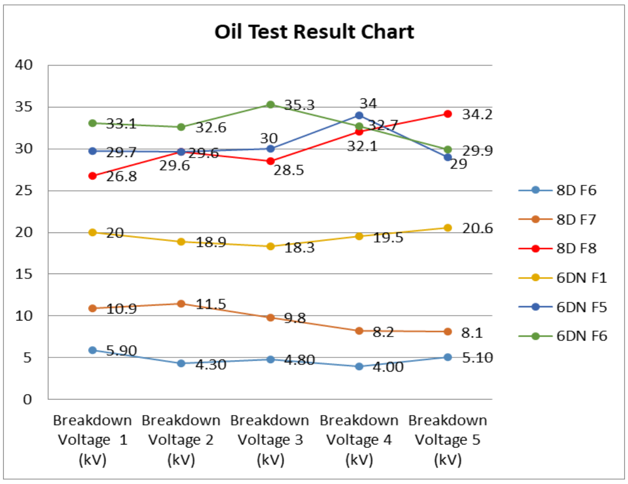

Figure 4: Graph of oil sample test results

Table 5: Calculation data of oil dielectric test results

No.	Feeder Name	Average Voltage (kV) $\bar{V}$	*Vh* (kV)	*Vl* (kV)	*V* Range (kV)	Validity Test <92% (%)
1	8D F6	4.82	5.9	4.0	1.90	39.42
2	8D F7	9.70	11.5	8.1	3.4	35.05
3	8D F8	30.24	34.2	26.8	7.4	24.47
4	6DN F1	19.46	20.6	18.3	2.3	11.82
5	6DN F5	30.46	34.0	29.0	5	16.41
6	6DN F6	32.72	35.3	29.9	5.4	16.50

Table 6: The Data of 13.8 kV OCB and insulating oil test results

No.	*OCB* Name	Service Life (Year)	Operating Frequncy *OCB* Manual	Operating Frequncy *OCB* Trip	Initial Color Level Before Operation (kV)	Initial Color Level After Operation (kV)	*ODS* Minimun (kV)	Description
1	8D F6	4	0	8	42	4.82	27	Fail
2	8D F7	3	3	3	45.6	9.7	27	Fail
3	8D F8	3	0	0	49.6	30.24	27	Pass
4	6DN F1	3	2	11	46	19.46	27	Fail
5	6DN F5	1	2	0	32	30.46	27	Pass
6	6DN F6	1	1	4	42.6	32.72	27	Pass

In addition to average value, the breakdown voltage range of test result was also calculated, namely calculating the difference between the highest value and the lowest value. The calculation results from the dielectric test are in Table 5.

The comparison graph of Oil Dielectric Strength (ODS) before and after operation, it can be seen in Figure 5. For 8D F6, there was a significant drop in breakdown voltage from 42 kV to 4.82 kV. Therefore, the oil was declared a failure due to it was below the minimum standard of 27 kV. The low breakdown voltage value occurs in accordance with physical observations found the presence of water droplets in the oil, thereby reducing the dielectric strength of the oil. In addition, its service life was 4 years with a frequency of 8 trips operating and exceeding its service schedule, which should be every 3 years. Inside the OCB there was water in the oil.

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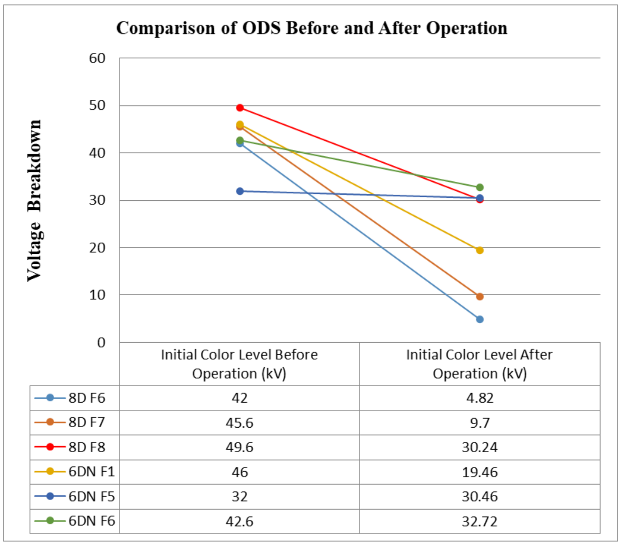

Figure 5: Comparison graph of ODS before and after operation

This is caused by a leak at the top of the OCB tank, namely the gasket bushing. At the time of sampling, the OCB was already turned off, and was immediately serviced.

In the 8D F7 feeder, there was also a drop in breakdown voltage, which was far from 45.6 kV to 9.7 kV. Then, the oil was declared a failure, because, it was below the minimum standard of 27 kV. The low breakdown voltage value was in accordance with physical observations of condition such as black oil with level 7, declared bad, and lots of carbon contamination. This OCB had been operating for 3 years with a manual operating frequency of 3 times and tripping 3 times. Also affected by a large normal load current of 248 A, so that the occurrence of heat and carbonization was faster and more abundant. Sampling was in a live OCB state, but would be serviced soon due to it has entered its 3 years schedule.

Feeder 8D F8 there was a drop in breakdown voltage from 49.6 kV to 30.24 kV. However, it has passed and still suitable for use to above the minimum 27 kV limit. In accordance with the results of physical observations, the condition of the oil was still in good condition with a color level of 1.5. This happens because the OCB 8D F8 had never operated either manually or trips due to disturbances even though operating for 3 years and approaching its service schedule. The service life has little effect on the color of the oil. Normal operating load was 189A. Sampling from this OCB was alive.

At 6DN F1, there was a significant drop in breakdown voltage from 46 kV to 19.46 kV. Therefore, the oil was declared fail due to below the minimum standard of 27 kV. The low breakdown voltage value was also in accordance with the results of physical observations of the condition of black oil with level 6, a lot of carbon contamination. This OCB had been operating for 3 years with a manual operating frequency of 2 times and trips 11 times. It was also affected by a large normal load current of 206 A. So, the occurrence of heat and carbonization was faster and more abundant. Sampling was in a state of OCB on, but a week of sampling. The OCB was turned off, because it would be serviced soon. It had entered its 3 year schedule.

For 6DN F5, there was a slight decrease in breakdown voltage from 32 kV to 30.46 kV. It was declared passed and still suitable for use, because, it was still above the minimum limit of 27 kV. In accordance with the results of physical observations was revealed the condition of oil still in good condition with same color level of 0.5. This happens because this OCB 6DN F5 has only operated manually 2 times, it has never been tripped due to interference. The service life of the OCB was only 1 year of use, with a small normal operating load of 60A. Sampling from this OCB was alive.

For 6DN F6, there was a significant drop in breakdown voltage from 42 kV to 32.72 kV. It was declared that the pass, which still above the minimum limit of 27 kV. The breakdown voltage was still high due to influence of the OCB's age, which has only been operating for 1 year and no contamination with liquid from outside. However, based on physical observations, the condition of the oil was black with level 6, a lot of carbon contamination. The poor condition of the oil was due to the influence of the manual operating frequency 1 time and tripping 4 times and influenced by a large normal load current of 198 A. Sampling was in a state of OCB on.

The relationship between the number of operations and the operating frequency of OCB with the dielectric strength (ODS) as shown in Figure 6. Figure 6 shows the relationship between the number of operating frequencies and the breakdown voltage value, where the higher the number of operating frequencies, the lower the breakdown voltage trend. The impact of this OCB operating frequently is that carbonization occurs due to a hot reaction with oil when the contact is separated, either during disturbance or manually separated. The relationship between the service life of OCB oil and Oil Dielectric Strength (ODS) is shown in Figure 7.

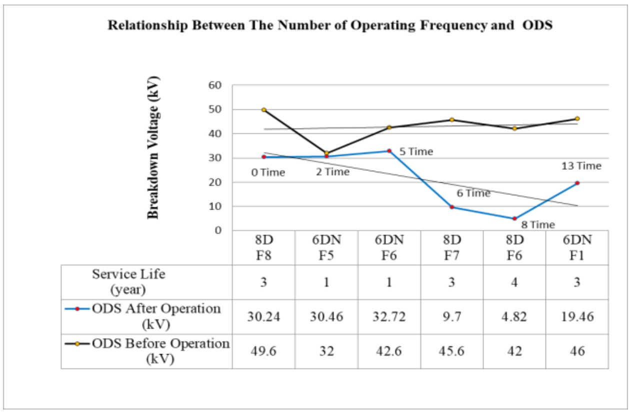

Figure 6: The graph of relationship between the number of operating frequencies and ODS

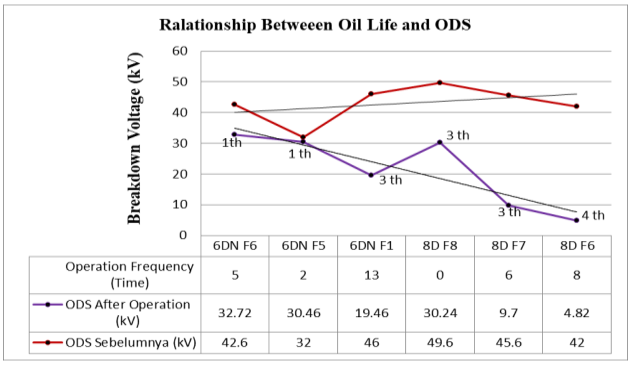

Figure 7: The graph of relationship between operating oil life and ODS

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Based on Figure 7, it can be seen that there is a relationship between the service life of the oil and the dielectric strength (ODS) of the oil. If the service life of oil is longer, then the breakdown voltage value is the lower. The decrease in the breakdown voltage value is influenced by the presence of solid and liquid contamination in the 13.8 kV OCB insulating oil both from internal and external. Even if the OCB never operates, the breakdown voltage value still decreases as happened in the 8D F8 of oil sample. The oil is in direct contact with the outside air through the ventilation holes of the tank. So, it is affected by humidity. Although it is not visible to the naked eye, there is a slight change in color.

4.0 CONCLUSION

From the research, it was found that a lot of operating frequency and oil age would be caused a visible color change in the 6DN F1 sample, which is yellow-black in color. The color level is from 0.5 to 6. There is a striking color difference, because it has been operating for 3 years with a frequency of 2 times the manual open and 11 trips with a large normal load of 206 A. In the 8D F7 feeder, there is also a decrease in breakdown voltage, which is far from 45.6 kV to 9.7 kV. So, the oil is declared failed, because it is below the minimum standard of 27 kV. For the validity test, the six samples are still within the allowable limits based on ASTM D1816 with the range value being below 92%, this means that the six samples are valid.

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