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Research Article

Behavior Analysis of Oil in Distribution Transformers Under Operating Conditions

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Abstract – Transformers are one of the devices that have a critical importance in the power system network in reaching the end consumer of alternating current electrical energy produced in power plants. It is a device used to convert the quantities of electrical energy. As a basic working principle, it is an electrical machine used to convert the voltage level by magnetic induction without changing the frequency. During the transmission of electrical energy from power plants to the end consumer, voltage transformation and power losses occur in the lines. In this study, transformer oil tests were used to reveal the behavior of 10 1600 kVA transformers in an industrial facility under operating conditions. The test results of oil samples taken from transformers in 2022 and 2024 were evaluated and analyzed comparatively. The behavior of transformer oils was examined under operating conditions. The effect of operating conditions on transformer oil was evaluated and the behavioral characteristics of the oil were revealed.

Keywords – Distribution Transformers, Transformer Oil, Oil Tests, Breakdown Voltage, Tanδ, Color Tests.

I. INTRODUCTION

Transformers are one of the devices that have a critical importance in the power system network in reaching the end consumer of alternating current electrical energy produced in power plants. It is a device used to convert the quantities of electrical energy. As a basic working principle, it is an electrical machine used to convert the voltage level by magnetic induction without changing the frequency. During the transmission of electrical energy from power plants to the end consumer, voltage transformation and power losses occur in the lines. In order to reduce these losses to a minimum level, it is necessary to keep the power constant [1]. For this, changes are made in the voltage level by means of transformers. In this way, losses are reduced and costs are reduced. Since these devices do not have a moving or rotating part, their structures are also simple. They contain a large amount of sheet metal plates and copper coils in their core. The current passing through the winding coils is the heat source. In order to reduce the electrical voltage, the winding coils are wrapped with insulation materials. The deterioration of their own chemical structure by heating these insulation materials is one of the main factors that determine the life of the transformer. Due to this negative effect of temperature, the temperature in transformers must be kept below a certain value [2]. In order to reduce the negative effects, the heat generated due to iron and copper losses in transformers must be removed from the transformer core. Oil cooling is the most basic cooling method among transformer cooling methods. It completely fills the transformer tank and cools the machine.

During operation, electrical partial discharge or even arcing may occur inside the transformer tank, which can lead to transformer oil degradation and eventually insulation failure. Both online and offline monitoring of the transformer insulation system is usually performed using different techniques such as dissolved gas analysis (DGA), partial discharge and dielectric response measurements [3].

The oils inside the transformer tank must provide insulation under high electric potential. If the dielectric strength of the transformer oil deteriorates, it becomes clear that the oil can no longer perform its function. Dielectric breakdown is caused by contaminants such as water, conductive particles, and residues of foreign substances. Transformer oil behavior analysis helps early detection of a failure in the transformer [4]. Periodic tests are an important method for determining behavioral changes. Deterioration in the oil is directly related to the refractive index of the transformer oil. The refractive index is a widely used method to evaluate the condition of the oil. As the oil ages under operating conditions, the refractive index value also increases linearly. As the refractive index of the oil increases, the breakdown strength, i.e. the breakdown voltage, decreases. Therefore, the refractive index change is of critical importance for evaluating the behavior of the oil [5].

In this study, transformer oil tests were used to reveal the behavior of 10 1600 kVA transformers in an industrial facility under operating conditions. The test results of oil samples taken from transformers in 2022 and 2024 were evaluated and analyzed comparatively. The behavior of transformer oils was examined under operating conditions. The effect of operating conditions on transformer oil was evaluated and the behavioral characteristics of the oil were revealed. The photograph taken during oil sampling is shared in Fig.1.

Fig. 1 Taking Oil Samples from Transformers

II. MATERIALS AND METHOD

The insulation level of the oil, safety and economy are of great importance in the continuity of transformers. It is observed that a significant portion of the failures in transformers are caused by the decrease in the quality of the oil used in the transformer [6]. In case of decrease in the quality of the oil used, foreign particles accumulated in the high electric field between the electrodes form a bridge and cause electrical breakdown to be easier.

Instead of solid particles in the insulating liquid, there may be water droplets, air bubbles or gas bubbles with lower breakdown resistance than the insulating liquid. In this case, complete breakdown of the insulating liquid may be triggered by the breakdown of water droplets (moisture) or air (gas) bubbles. For these reasons, Tanδ, Breakdown Voltage, Water Amount, Acidity, Internal Surface Tension, Color and Density tests of transformer oils should be performed at certain periods.

The element that causes the breakdown in the oil layer between two standardized spherical headed electrodes, which are 2.5 mm apart, is the voltage. Its value is determined as kV. Breakdown voltage is the most important feature that characterizes the electrical insulation ability (voltage resistance level) of the oil. High amounts of moisture cause water accumulation and pollution, which reduce the breakdown voltage. Loose materials, metal parts, fibers, dust and carbon particles reduce the breakdown resistance [6-8].

Internal surface voltage test; shows the presence of ionized contamination in transformer oil. As the sludge increases, the coil surfaces are covered with sludge. Cooling and electrical problems occur [6-8].

As oxidation increases, the amount of acid also increases. Acids affect the metal surfaces in the transformer and increase saponification. In addition, they affect the cellulose and damage the insulation [6-8].

The dielectric dissipation factor, tanδ, is the ratio of the active and reactive currents flowing from the container where the transformer oil sample is measured. The tanδ value also increases with the aging of the oil, contamination with water and the other particles [6-8].

One of the important reasons that negatively affects the electrical properties of the oil is the amount of water and oxygen in the oil. The amount of water in the paper insulation, especially together with the presence of oxygen, is one of the parameters that determine the life of the transformer [6-8].

The color of the oil gradually changes (darkens) in the long term in operation. The darkening of the color of the oil in the operation is a sign of oxidation and reaction (aging) [6-8].

III. RESULTS

In this section, the test results of oils taken from 10 distribution transformers in the industrial enterprise are shared. The behavior of transformer oils after two years of operation was analyzed. Comparative evaluations were made. While the test results of oil samples for 2022 are presented in Table 1, the oil test results for 2024 are given in Table 2.

Table 1. Results of Transformer Oil Test in 2022

Parameter	TR-1	TR-2	TR-3	TR-4	TR-5	TR-6	TR-7	TR-8	TR-9	TR-10
Tanδ	0.008	0.002	0.005	0.005	0.008	0.005	0.004	0.029	0.020	0.026
Breakdown Voltage (kV)	54	70	65	81	70	80	77	45	60	70
Water Amount (ppm)	12.9	2.2	7.6	7.9	4.5	6.8	5	5.2	9.6	7.2
Acidity	0.009	0.01	0.005	0.006	0.006	0.005	0.01	0.005	0.007	0.005
Internal Surface Tension (mN/m)	35	37	35	34	32	22	41	25	26	26
Color	0.5	0.5	1.5	1.5	1.5	2	0.5	1.5	1.5	2
Density (g/cm^3)	0.881	0.881	0.885	0.885	0.878	0.878	0.877	0.878	0.877	0.880

When the data in Table 1 is examined, it is seen that the highest dielectric loss factor value is in TR-10 with 0.026. The lowest dielectric loss factor value is measured as 0.002 in TR-2. According to the breakdown voltage measurement results, it is observed that the TR-8 transformer oil is quite close to the critical value of 40 kV. The highest breakdown strength is determined to be in TR-4 with a value of 81 kV. When the amount of water in the transformer oil is taken into consideration, it is revealed that TR-1 contains considerably more water than all other transformers. The oil of TR-2 transformer has the lowest water bar. The color codes of the oils in the transformers are described as clear and light colored. The transformer with the darkest color is determined as TR-6 with a value of 2. The graphical layout of the data for all transformers is shared in Fig.2. Thus, comparison of transformers can be made easily in specific tests.

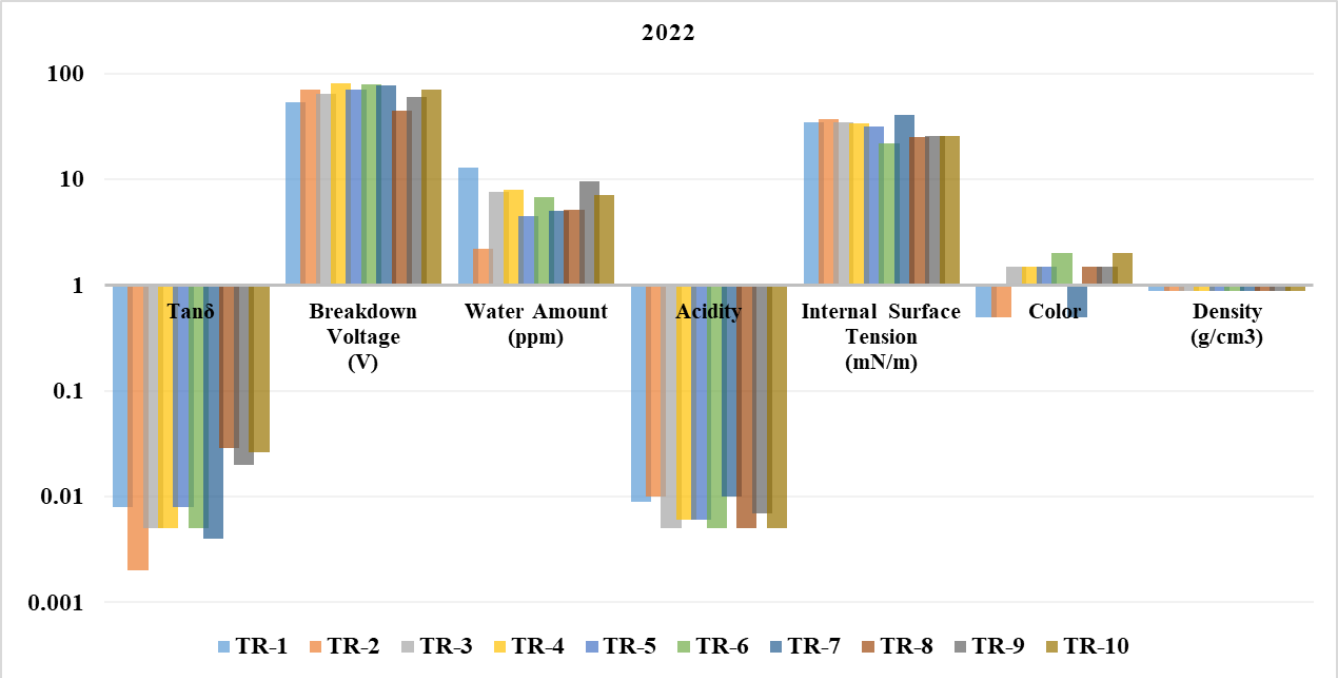


Fig. 2 Results of Oil Tests in 2022

Table 2 shares the results of oil tests carried out in 2024. The general trend emerging from the results is that transformers wear out under operating conditions.

Table 2. Results of Transformer Oil Test in 2024

Parameter	TR-1	TR-2	TR-3	TR-4	TR-5	TR-6	TR-7	TR-8	TR-9	TR-10
Tanδ	0.006	0.011	0.008	0.008	0.017	0.006	0.006	0.061	0.025	0.026
Breakdown Voltage (V)	62	64	54	50	50	67	60	64	46	70
Water Amount (ppm)	7.4	8.4	12.9	12.1	10.9	9.7	9.7	10	11.4	9.8
Acidity	0.007	0.01	0.006	0.006	0.006	0.008	0.008	0.008	0.008	0.007
Internal Surface Tension (mN/m)	33	35	33	32	31	24	35	24	24	25
Color	1	1	2	2	2	2.5	1	2	2	2.5
Density (g/cm^3)	0.872	0.888	0.886	0.886	0.878	0.878	0.877	0.877	0.877	0.881

When the data in Table 2 is examined, the dielectric loss factor occurred the most in TR-10. The TR-10 dielectric loss factor value was measured as 0.026. While TR-9 came first with the lowest value in the breakdown voltage ranking, TR-10 was the last and most durable transformer with the highest value. The TR-10 breakdown voltage value was determined as 70 kV. The test results for the amount of water in the oils are quite surprising. 12.9 ppm of water was detected in the TR-3 transformer oil. It was also observed that the amount of water in the oils increased compared to 2022. In addition, it was determined that the color codes of the oils increased. In this context, it was revealed that aging symptoms caused by operating conditions can be detected with color code test results. In Fig.3, the results of the oil tests for 2024 are presented in graphical form. Thus, the test results can be easily compared for transformers.

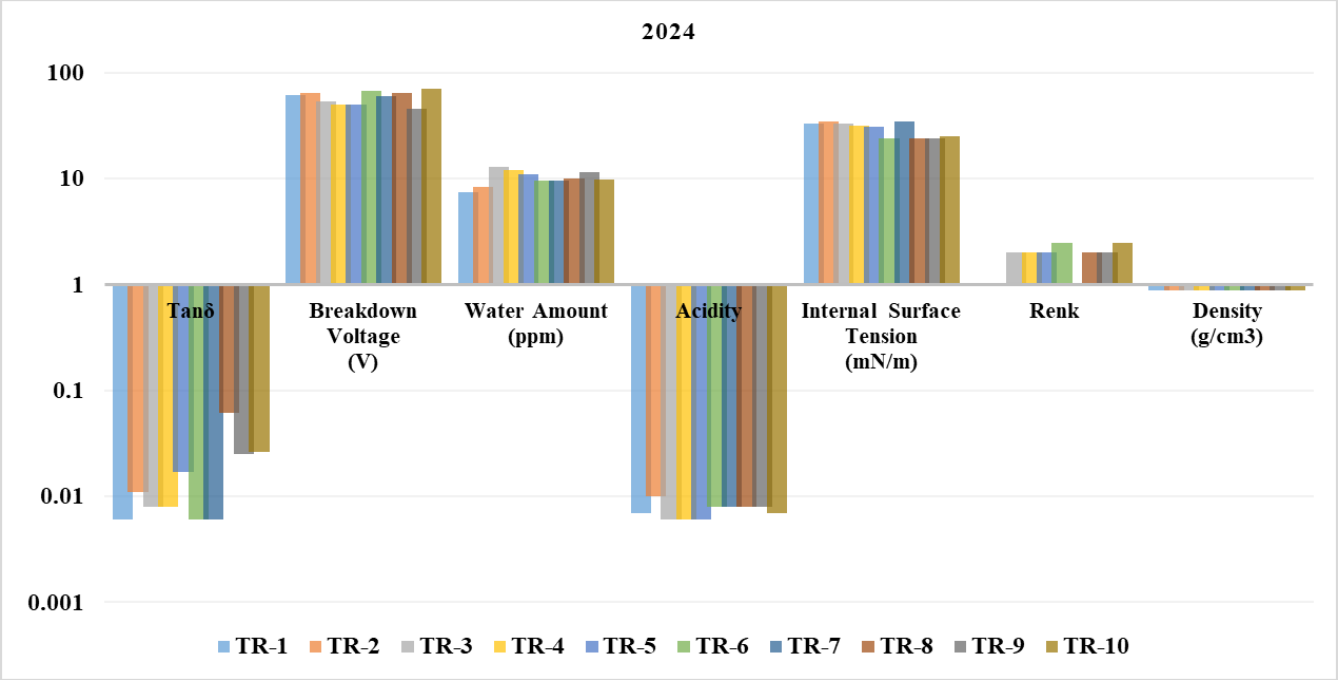
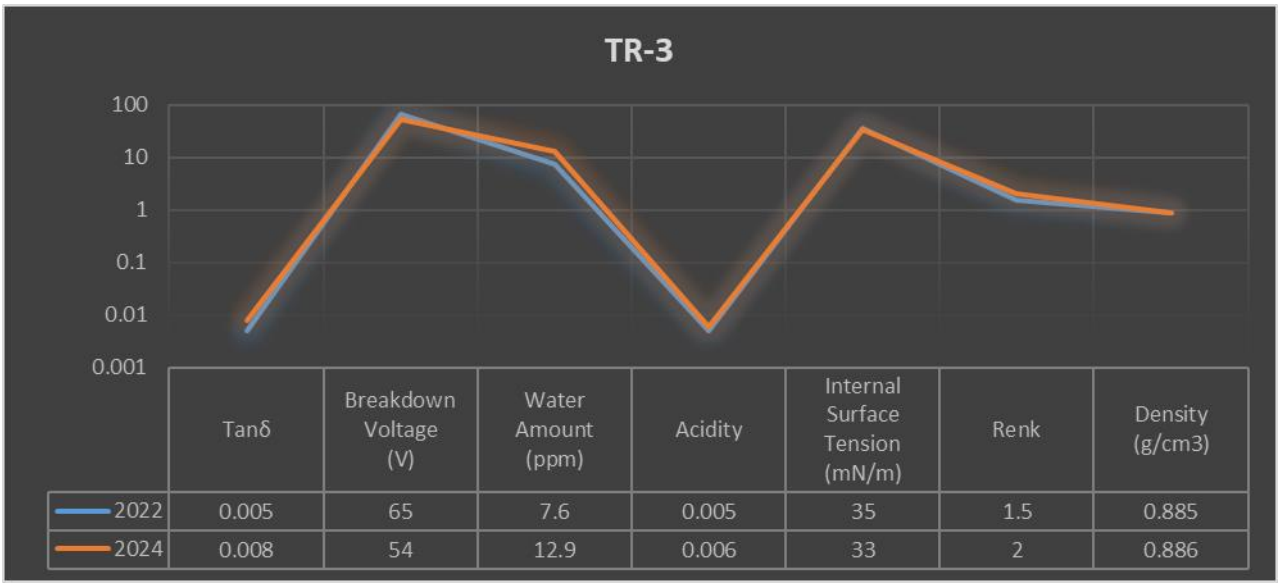


Fig. 3 Results of Oil Tests in 2024

IV. DISCUSSION

In this section, the test results are discussed in detail on a transformer basis and evaluated comparatively with the test results obtained over the years. In Fig.4, the transformer oil test results for TR-3 in 2022 and 2024 are presented.



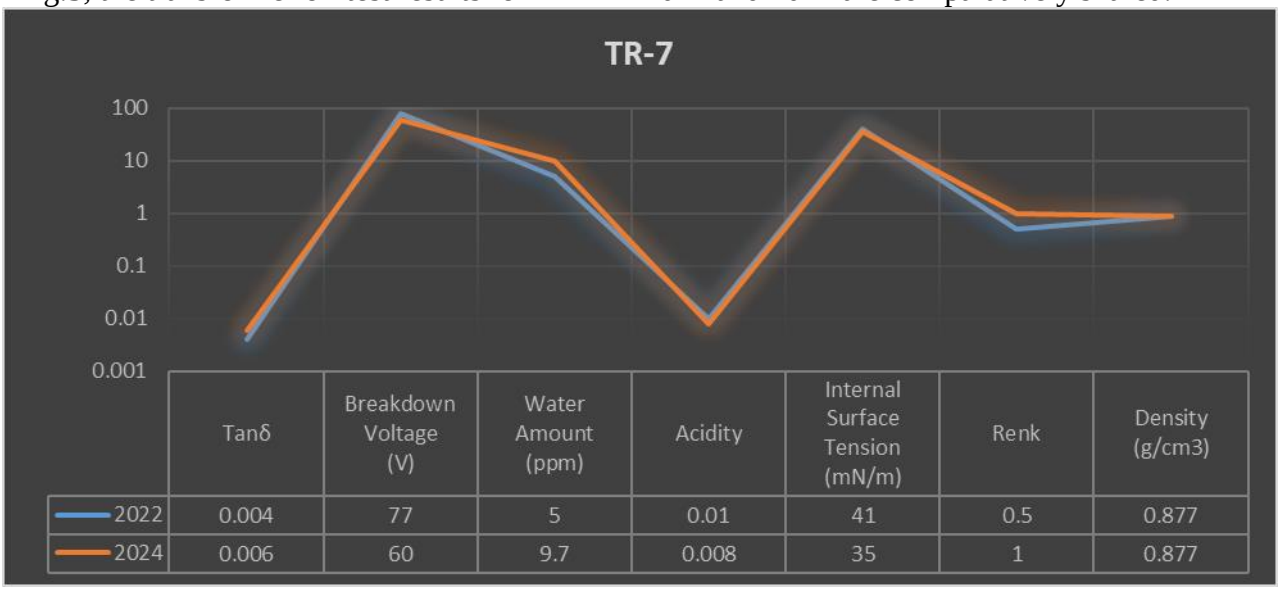
	Tanδ	Breakdown Voltage (V)	Water Amount (ppm)	Acidity	Internal Surface Tension (mN/m)	Renk	Density (g/cm3)
2022	0.005	65	7.6	0.005	35	1.5	0.885
2024	0.008	54	12.9	0.006	33	2	0.886

Fig. 4 Results of Oil Tests for TR-3

When the behavior of the TR-3 transformer under operating conditions was evaluated, it was determined that the dielectric loss factor increased within two years of operation. This indicates that the oil is aging. It was determined that the breakdown voltage value decreased from 65 kV to 54 kV. Both of these values are above the limit value of 40 kV.

Within two years, the amount of water in the transformer oil increased from 7.6 ppm to 12.9 ppm. In this context, it was found that the oil held moisture and it was determined that the transformer air dryer equipment did not fulfill its function. As a result of the aging of the transformer oil, the color code was measured as 1.5 in 2022 and 2 in 2024.

In Fig.5, the transformer oil test results for TR-7 in 2022 and 2024 are comparatively shared.



	Tanδ	Breakdown Voltage (V)	Water Amount (ppm)	Acidity	Internal Surface Tension (mN/m)	Renk	Density (g/cm3)
2022	0.004	77	5	0.01	41	0.5	0.877
2024	0.006	60	9.7	0.008	35	1	0.877

Fig. 5 Results of Oil Tests for TR-7

When the data in Fig.5 is examined, it is seen that the dielectric loss factor of the TR-7 transformer oil has increased by 50% and increased from 0.04 to 0.06. Meanwhile, the breakdown voltage value has decreased from 77 kV to 60 kV. In this case, it has been determined that the transformer has aged under operating conditions. The amount of water in the transformer oil has approximately doubled. The presence of water, which was 5 ppm in the measurements made in 2022, reached 9.7 ppm in 2024. In this case, it has been determined that the silica gel material in the air dryer does not fulfill its function. The color code of the transformer oil has increased from 0.5 to 1. Thus, it has been obtained that the oil color has darkened and turned from light yellow to dark yellow.

V. CONCLUSION

In this study, transformer oil tests were used to reveal the behavior of ten transformers in an industrial facility under operating conditions. The test results of oil samples taken from transformers in 2022 and 2024 were evaluated and analyzed comparatively. The behavior of transformer oils was examined under operating conditions. The findings obtained from the oil tests are shared below;

- As a result of operating conditions, the dielectric loss factor value of transformer oils has increased noticeably.
- The breakdown voltage value tends to decrease.
- The breakdown voltage of all transformer oils has not been broken below the 40 kV threshold value.
- The amount of oil in transformer oils has increased between 50% and 100%.
- It has been determined that the air dryer equipment of transformers does not fulfill its duty.
- The color codes of transformer oils that are worn and strained under operating conditions increase linearly.

Behavioral analysis of transformers and transformer oils facilitates us to obtain information about operating conditions. In future studies, it is planned to evaluate the gases dissolved in transformer oils. Thus, it is aimed that fault detection will be possible with behavioral analysis.

REFERENCES

[1] A. Koochaki, S. M. Kouhsari, and G. Ghanavati, ``Transformer internal faults simulation," Adv. Electr. Comput. Eng., vol. 8, no. 2, pp. 23-28, 2008.

[2] M. Duval, ``A review of faults detectable by gas-in-oil analysis in transformers," IEEE Elect. Insul. Mag., vol. 18, no. 3, pp. 8-17, May 2002.

[3] A. Akbari, A. Setayeshmehr, H. Borsi, E. Gockenbach, and I. Fofana, ``Intelligent agent-based system using dissolved gas analysis to detect incipient faults in power transformers," IEEE Elect. Insul. Mag., vol. 26, no. 6, pp. 27-40, Dec. 2010.

[4] M. -J. Lin, L. -B. Chen and C. -T. Yu, "A Methodology for Diagnosing Faults in Oil-Immersed Power Transformers Based on Minimizing the Maintenance Cost," in IEEE Access, vol. 8, pp. 209570-209578, 2020, doi: 10.1109/ACCESS.2020.3038827.

[5] K. Assaleh and A. El-Hag, “Estimating Transformer Oil Parameters Using Polynomial Networks”, Intern. Conf. Condition Monitoring and Diagnosis, Beijing, China, pp. 1335-1338, 2008.

[6] S. Abdi, A. Boubakeur, and A. Haddad, “Influence of thermal ageing on transformer oil properties”, IEEE Intern. Conf. Dielectric Liquids, pp. 1-4, 2008.

[7] Hussain, M., Mir, F. A., & Ansari, M. A. Nanofluid transformer oil for cooling and insulating applications: A brief review. Applied Surface Science Advances, 8, 100223, 2022.

[8] Senoussaoui, M. E. A., Brahami, M., & Fofana, I. (2021). Transformer oil quality assessment using random forest with feature engineering. Energies, 14(7), 1809.